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All communications should be addressed to the Editor.

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Notices of the Royal Aëronautical Society.

Election of Members.

The following members were elected at a Council Meeting held on September 20th:—

Associate Fellows.—Wing Commander H. R. Busteed, O.B.E., A.F.C., Herbert Carrington, B.Sc.
Student.—G. Reid.
Member.—W. H. Tripp.

Paris Air Congress.

In response to an invitation received from the French Air Attaché, the Council have nominated the Chairman (Lieut.-Col. M. O'Gorman) and the Secretary to act as their representatives at the International Air Congress to be held in Paris during November.

Students' Discussion Meetings.

Dr. L. Bairstow presided at a meeting of students held at the Society's offices, on September 19th, when it was decided provisionally to hold meetings in the Library at 7.0 p.m., usually on the second Thursday in each month. These meetings will be for students only, with a member of the Society in the chair, and at each a discussion will be inaugurated by the reading of a paper by a student. These papers will be adjudicated upon by the Council at the end of the Session and the Pilcher Memorial Prize for Students awarded to the one which is considered to be the best. It was decided not to elect any officers for the Students' Section at the moment, with the exception that Mr. Stanley Evans was invited to continue to act as Honorary Secretary *pro tem.*

The following promises of papers were received:—

October 13th.—T. A. Kirkup on "A Comparison of Different Types of Aerofoils."
November 10th.—W. L. Le Page on "The Soaring Flight Problem."
December 8th.—Colin Daniel.
January 26.—S. R. Irvine.

All papers must be in the Secretary's hands at least three clear days before the date of reading.

Books Required.

The following books are urgently required for the Library. The Secretary will be very grateful if any member, who has spare copies of any of them, would be so kind as to present them :—

Chemistry.

" Rubber, Resins, Paints and Varnishes," R. S. Morrell and A. de Waele.
" Handbook on Sampling and Testing," Manchester Chamber of Commerce Testing Laboratory.
" La Cellulose," L. Clement and C. Riviere.
" Technology of Cellulose Acetates," Warden. Vol. VIII.
" Liquid Fuel for Internal Combustion Engines," Archbutt and Dieley.

Construction.

" Aeroplane Timbers," G. R. Keen.
" Strength of Materials," G. Morley.
" Theory of Structures," G. Morley.
" The Heat Treatment of Steels," H. Brearley.

Engines.

" Gas, Petrol and Oil Engines," Vols. I. and II., D. Clerk and G. A. Burls.
" Thermodynamics for Engineers," J. A. Ewing.

Meteorology.

" Manual of Meteorology," Part IV., Sir Napier Shaw.
" Forecasting Weather," Sir Napier Shaw.
" Principles of Aerography," McAdie.

REFERENCE BOOKS.

Chemistry.

" Dictionary of Applied Chemistry," Thorpe.

Light Alloys.

" Aluminium Alloys Reports," American Bureau of Standards.
" Light Alloys Committee Reports " (VII., IX. and XI.), Inst. of Mech. Engineers.

Books Received.

The following books and pamphlets have been received and placed in the Society's Library :—" A Text-Book of Aeronautical Engineering. The Problem of Flight " (3rd Edition), by Dr. H. Chatley ; " Kite Balloon Winch Manual " (Air Publication 817) ; " An Introduction to Physics for Technical Students," by P. J. Haler and A. H. Stuart ; " Who's Who in Engineering," by the Compendium Publishing Company.

Arrangements for the Month.

Oct.	5, 11.0 a.m.	Special Meeting of Council.
,,	6, 5.30 p.m.	Lecture by Air Commodore Brooke-Popham on " Aeroplanes in Tropical Countries," Royal Society of Arts, Adelphi, London.
,,	13, 7.0 p.m.	Students' Discussion Meeting, T. A. Kirkup on " A Comparison of Different Types of Aerofoils."
,,	17, 8.0 p.m.	*Scottish Branch.*—Lecture by Col. V. C. Richmond on " The Organisation of a Colonial Airship Service," Engineering Class Room, Glasgow University.

Oct. 18,	4.0 p.m.	Publications and Library Committee.
	4.30 p.m.	Candidates' Committee.
	5.0 p.m.	Council Meeting.
,, 20,	5.30 p.m.	Lecture by Mr. Griffith Brewer on "The Langley Machine and the Hammondsport Trials," Royal Society of Arts, Adelphi, London.
,, 31,	8.0 p.m.	*Scottish Branch.*—Lecture by Professor Gordon Gray on "Research Work on the Application of Gyroscopes to Aviation," Natural Philosophy Class Room, Glasgow University.

Members do not require tickets for lectures, but can obtain them for their friends on application to the Secretary.

W. LOCKWOOD MARSH, *Secretary.*

R38 MEMORIAL FUND.

The following letter, signed by the President, has been sent to the Editor of "The Times." Donations towards the fund, for which a separate banking account has been opened, should be sent to the Secretary:—

28th September, 1921.

To the Editor of "The Times,"
Printing House Square, E.C.4.

SIR,

The Council of the Royal Aeronautical Society have decided to establish a Memorial Fund, to commemorate those who have been lost in R.38 and in previous airships, and to be called the "R.38 Memorial Fund."

It is proposed to invest the capital and devote the income to the encouragement of investigation into problems connected with airships or allied subjects, which course it is felt would best meet the wishes of the relatives of those who have given their lives in the cause of airships.

As is now well known, it has been decided to suspend all Government work on airships, and it is probable that little or no provision will be made for the continuance of experimental or research work. It is, however, of paramount importance that some such work should be proceeding, on however small a scale, pending the time when the resumption of an airship service is decided upon. A sufficient capital sum to provide an annual grant towards the carrying out of some specific investigation—on a large or small scale according to the amount available—would, it is felt, be a valuable aid during this hiatus, and the period of reconstruction following it, and would serve as some safeguard, even though perhaps a slight one, against the complete neglect of airship possibilities. It is proposed that the results of the investigation should be embodied in a paper or papers to be read before the Members of the Royal Aeronautical Society.

I therefore beg to ask you to grant me the hospitality of your columns to invite your readers to forward contributions to this fund to the Secretary, Royal Aeronautical Society, 7, Albemarle Street, London, W.1.

Yours faithfully,

(Signed) WEIR,
President.

SCOTTISH BRANCH.

ANNUAL MEETING.

The future of commercial aviation and the function of the British cross-Channel services in providing experience for the development of the industry were discussed by Lord Weir of Eastwood, President of the Royal Aeronautical Society, who presided at the Annual Meeting of the Scottish Branch of the Society, which was held in the hall of the Institute of Engineers and Shipbuilders on Monday, September 19th. The annual report, already published, was submitted by the Hon. Secretary, Mr. J. Buyers Black.

Lord WEIR said it gave him great pleasure to be present and to move the adoption of the report, which reflected the greatest possible credit on the Scottish Committee and its noble Chairman, and on the work of their indefatigable Secretary, Mr. Buyers Black. It was with feelings of the deepest regret that he referred to the unique losses which their Air Force had had to bear. In the first case they had to lament the loss of one whom many of them knew and looked upon as the most knightly figure in their British aviation world, General Sir David Henderson. Many tributes had deservedly been paid to him. He was the first man, or at least the first soldier in Great Britain, to grasp in a practical manner the vast possibilities of aircraft as a weapon of war. To the progress of aviation he sacrificed an undoubtedly great future as a soldier, but he became the greatest influence and the greatest personality in British military aviation. He created the Royal Flying Corps, and later on he exercised a dominating influence in the creation of the Royal Air Force. That was not generally known, but it was the case. Almost coincident with General Henderson's death came one of the greatest disasters ever suffered by the Royal Air Force, the loss of the R38. The airship might be replaced, but the individuality and character of such men as Commodore Maitland and others was quite irreplaceable. They recalled that Commodore Maitland's last public appearance in the cause of aviation was in Scotland under the auspices of the Scottish Society, when on March 14th he addressed a meeting of public school cadets. The influence of the disaster on the immediate development of lighter-than-air craft could not be ignored. He (Lord Weir) was perfectly convinced that a very successful step was taken in asking the great Dominions and Colonies to take a share in the responsibilities of that decision. The future of the airship meant much more to those Dominions in every eventuality than to us in these islands.

Passing for a moment from the airships, any review of British aviation and of the progress made during 1921 would be quite incomplete if it did not embrace some reference to the situation in regard to heavier-than-air service across the English Channel. He had had the honour to be Chairman of the Advisory Committee on Commercial Aviation since the Armistice, and in the recommendations of that Committee, along with others, he had laid great stress on the necessity for concentration of effort on these services, because he believed that those services must offer the best opportunities for the display of British air transport enterprise anywhere in these islands. For those reasons he had consistently pressed the Air Ministry and the Government to offer the most encouraging possible conditions to British enterprise on the cross-Channel services.

Lord INVERNAIRN seconded the adoption of the report. He said they were looking forward to a very interesting session. They would be interested to learn from the report that Glasgow would be one of the centres in which it was intended to move actively in the near future, and it was incumbent upon them to seize the opportunity offered Glasgow to take a first-hand interest in aviation. It was

gratifying to know that the Air Ministry had retained for the present, under a lease of five years, Renfrew Reception Park, and they might look forward before long to making some practical use of it for their students at the University. That was one of the subjects which would engage the attention of the Scottish Executive in the course of the next year.

The report was approved, and on the motion of Mr. Harold Yarrow, seconded by Sir John Reid, the Executive Committee were re-elected.

Progress in Canada.

A communication from Mr. Norman A. Yarrow, Victoria, British Columbia, on "Commercial Aviation in Canada," was read by Mr. Buyers Black. Mr. Yarrow, in the course of his Paper, said that in the development of commercial aviation the two watchwords must be "safety" and "reliability." There was a huge amount of survey work with the camera to be done by means of the air, together with the protection cruises of the forest against fire. Aircraft to-day in Canada was just as the automobile was fifteen years ago. In Canada there were 30 firms engaged in operating aircraft, and between May 1st and October 31st, 1920, 422,000 miles had been flown and 15,000 passengers carried. Taking into consideration that no aerial transport took place till after the signing of the Armistice, they had made a fair start.

THE MANŒUVRES OF GETTING OFF AND LANDING.*

BY SQUADRON LEADER R. M. HILL, M.C., A.F.C.

PART I.—INTRODUCTION.

1. General Remarks.

The manœuvres of getting off and landing are to me the beginning and the end of flight; they separate the sheep from the goats; the aristocrat of the flying world uses them for the display of his genius, leaving his would-be imitators to find what consolation they can in the amusement with which they innocently provide the onlookers.

In commercial flying the manœuvres of getting off and landing are still the most obvious calls on the pilot's skill; and who shall deny the splendid response? But a determination to ease the pilot's task is not thereby for an instant to be excused. This, one of the most urgent problems before applied design to-day, lies in the conflicting requirements of ease and safety in getting off and landing and those of economy and usefulness in full flight. To assist in the statement of this problem is the object of my Paper. These are the manœuvres perhaps about which most has been said, and, from the pilot's point of view, least written. Since first a heavier-than-air machine left the ground, they have never failed as a topic of conversation throughout the whole flying community; and this has tempted me to analyse them on the basis of my own experience and that of the many pilots I have known.

Theoretical analyses of these manœuvres, while endowing the assumed pilot with human characteristics, have of necessity to envelop in a hypothetical average the diverse individual variations. Yet, in practical flying, proximity to the ground in the neighbourhood of stalling point throws into stronger relief than at any other time human variations in handling. There are many classes of pilot in whose flying various degrees of intelligence and instinct are blended; and each class has its own way of meeting the difficulties and ensuring what it considers to be the maximum of safety. So it is difficult to make a sweeping generalisation. At the same time, almost independently of the quickness of a get off, or the slowness of a landing, it is possible to recognise in it what is termed good or bad style, something which can or cannot be identified with cleanness of handling, reliability and a sense of mastery.

The manœuvres of getting off and landing may be divided into two classes; firstly those under normal and satisfactory conditions, with reasonably good ground and sufficient space for the pilot to get off and land without taking into account any limitations save those of his aeroplane; and secondly what are termed forced manœuvres, manœuvres in which the pilot is limited in some way; for example, getting off in a confined space, over unnaturally high obstacles or on bad ground, or, after engine failure, judging a landing in an unknown field.

A forced landing with an aeroplane on which a pilot is experienced is frequently taken as the ultimate test of his powers of foresight, judgment and flying capacity; if then he is not quite at home on the particular type he is flying, his difficulties in forced manœuvres will be increased tenfold. Yet the pilot has even now, due to the imperfection of the aero engine, to face the possibility of a forced manœuvre on types with which he is unfamiliar before he has had the chance to become experienced on them; and so such manœuvres are worth all the study and preparation beforehand that he can possibly give.

* Lecture to be delivered before the Society, November 3rd.

2. The Nature of "Getting Off" and "Landing."

The manœuvre of getting off will be taken to commence with the opening of the throttle when the aeroplane is at rest, and to conclude with the condition of steady climb free from the embarrassing proximity of the ground; that of landing to extend from the moment that the pilot is influenced by the necessity of approaching a definitely limited landing space, to the time when the aeroplane is again at rest on the ground.

When the pilot is about to take off the ground he realises that his craft is not supported by the element in which he is going to fly and manœuvre, but by its wheels and tail skid as it rests on the ground. From the moment he opens the throttle until his wheels leave the ground, the conditions of his support undergo a gradual translation, leading up, as it were, to the moment when he is completely air borne. During the translational period the aeroplane often shows characteristics alien to normal flight, which are apt to deceive the pilot as to what it is going to feel like in the air. Although the translation from ground to air conditions has been referred to as gradual, the process is further complicated because in practice the ground is rarely smooth enough to allow the pilot to get off without several bounces, which may disturb his well-laid plans. Neither can the pilot be said to have completed his getting off until he is climbing steadily well clear of the ground. As long as he is low down, the nearness of the ground exerts on his handling of the aeroplane a powerful influence, from which he cannot shake himself free until he is at least 1,000ft. up. The whole process of getting off may roughly be divided into *three phases*: that in which the aeroplane is chiefly supported by the ground; that in which it is mainly air-borne, but not uninfluenced by the contact of its wheels with the ground; and that in which it is wholly air borne and the pilot is adjusting his flight to the condition of steady climb and getting clear of the ground.

Again, when the pilot flies his aeroplane towards the aerodrome to make a landing he realises that, taking into account the angle of his glide, he must bring his aeroplane to a position close to the ground and in a condition of flight such that the translation from air to ground conditions may ensue immediately and in a kindly manner; and that, to reduce the chances of damage to a minimum and to use up the least space before coming to rest, the subsequent run, in which ground conditions prevail, will be as short as possible. In contra-distinction to getting off, the process of landing may be divided into *two phases*: that in which the aeroplane is air borne and in which the pilot is adjusting his flight so as to ensure favourable conditions for approximation to and contact with the ground; and that in which the aeroplane runs along the ground before coming to rest. The modern idea of landing excludes the phase in which the aeroplane is allowed to run along the ground with the tail up. The first phase, though somewhat complex, is difficult to sub-divide, for the onset of the influence of the ground is intimately bound up with the pilot's preliminary efforts to bring about conditions favourable to a good landing. Should these efforts have been ill-judged, the pilot's subsequent attempts at correction may serve rather to embarrass his landing than assist it; and what is more important, he is tempted to forget his rapidly receding powers of manœuvre, and under the influence of the increasingly urgent necessity of reaching favourable conditions prior to contact with the ground, he may ask more of the aeroplane than it can give.

It is only when the pilot has yielded to this temptation that the relative frailty of the structure of an aeroplane is brought home to him; he then realises how small a shock it need sustain to break, and how, if the maximum safe vertical drop on its wheels be small, a drop in which lateral or turning motion is included is many times smaller. Improvement of undercarriages in the properties of shock absorption and capacity to resist lateral loads may do much to mitigate errors in judgment, but it is well to emphasise how sure must be the pilot's judgment of the correct attitude of the aeroplane before contact with the ground

is contemplated, when the speed at which he must necessarily be travelling and the possible unevenness of the contour of the ground is taken account of. The average pilot has to fly for some time before his sense of the translation from air to ground conditions is sufficiently vivid to make him really reliable. When he is air borne and clear of the ground in a highly controllable aeroplane, a mere bank of 20° or so is hardly differentiated in his mind from rectilinear flight, so distantly related is it to the limiting kind of manœuvre which a pilot may not exceed without risk of breaking the aeroplane, and which is peculiarly confined to air handling. Not so when he is going to make contact with the ground. He is suddenly compelled to change his mental attitude towards the aeroplane; and this needs a distinct effort. Otherwise with a 20° bank on he may catch a wing-tip and turn the aeroplane on its back. A shock that the pilot hardly feels may be the prelude to a crash sufficient to "write off" the aeroplane. Many pilots, even those with considerable experience, have, after carrying out some violent "S" turns when manœuvring for position, suddenly realised that the ground is close and that the aeroplane is going to strike it; yet due to the persisting influence of air conditions have not made sufficiently drastic efforts to right the aeroplane, and so have crashed. The necessity of marshalling the aeroplane to a definite spot not only as regards position but as regards height, and, within small limits, of being at a definite speed at this spot, taken in conjunction with the sense of air freedom which the pilot has been enjoying, seems to constitute the psychological difficulty of landing well and safely.

3. Factors which influence "Getting Off" and "Landing."

The essential factor that influences the manœuvres of getting off and landing is the stalling speed of the aeroplane. The aeroplane must be somewhere near to the lowest speed at which flight can be maintained when its wheels leave the ground and when they again make contact with it. To this speed the pilot's mind sub-consciously makes reference. Therefore the flying qualities of the aeroplane at and near stalling speed influence the getting off and landing very powerfully. In flight these qualities can always be felt as distinct from those at high speeds, but they vary in different types of aeroplane due to loading, stability characteristics and relative size of the aeroplane, on which three factors, assuming normally designed control surfaces, the control seems chiefly to depend. And it is with the control, which is built on these foundations, that the pilot is vitally concerned. In getting off, the relative power of the engine will also influence the flying qualities near stalling. Unfortunately, as is well known, the flying qualities near stalling make a bigger demand on the control than those in any other attitude of flight; but owing to the low air-speed, this is just what the control surfaces cannot afford. Simultaneously with manœuvring for favourable conditions, the pilot must be ready to counteract large disturbing forces. Therefore according to his skill and the qualities of his aeroplane he is compelled to leave himself a certain margin of speed in excess of stalling.

At stalling two unpleasant characteristics assert themselves; a large couple comes into play tending to put the nose down, and the aeroplane tends to become laterally highly unstable in straight flight; in other words the aeroplane at the full ebb of the pilot's controlling powers, does its utmost to bang its wheels or its wing tip on the ground. The pilot is naturally anxious to leave the ground as soon as he is air borne, because, even assuming there are no abnormal obstacles to surmount, he wishes to be at the maximum possible height over the edge of the aerodrome in case of engine trouble; if he allows the wheels to continue running over the ground at a speed greater than is absolutely necessary, the aeroplane is sure to be bumped about and the last phase of its get-off impaired: that is, when it reaches the edge of the aerodrome its height will have been reduced. At the same time the pilot dare not cut short prematurely

the second phase of getting off while his controls are feeble and the disturbing forces large.

The foregoing remarks may be summed up by saying that the pilot always wishes, both in getting off and landing, to reduce the period in which his wheels are in contact with the ground and running over it, provided that in doing so he does not render the air-borne conditions just after or prior to contact with the ground so unfavourable as to be dangerous.

PART II.—"GETTING OFF."

1. Factors which particularly influence "Getting Off."

The principal factors which influence the pilot's handling in the manœuvre of getting off may be summarised thus :—

(*a*) The absolute dimensions of the aeroplane.
(*b*) The loading.
(*c*) The power of the engine or engines relative to the area and the weight.
(*d*) The position and effect of the propeller slipstream or slipstreams.
(*e*) The stability characteristics, assuming reasonable balance; and the effects of lack of balance.
(*f*) The control surfaces and their effectiveness, especially at low speeds.

Less important factors may be considered as :—

(*g*) The height, relative position and character of the undercarriage.
(*h*) The angle of the aeroplane to the ground with the tail down, and the height of the wings above the ground.
(*i*) The pilot's view of the ground, the contour of the fairing in front of him, and his position with regard to the C.G. and to the wings.

(*a*) In general, aeroplanes may be classified in size under four heads. The scout type, which includes aeroplanes of anything up to 300 sq. ft. in area; the larger single-engined two or three passenger type up to 800 sq. ft. in area; the twin-engined type up to 2,000 sq. ft. in area; and the large multi-engined aeroplane of 2,000 sq. ft. in area and upwards. The absolute dimensions give a fair measure of the liveliness of the aeroplane's motion in the air, and the magnitude of the control forces that the pilot may be called upon to exert. Small aeroplanes feel lively in the air, yet on the whole are the more readily controlled; large aeroplanes feel sluggish, but the control forces are greater and the response to the controls is slower. So for the inexperienced pilot, a medium sized aeroplane of 400 to 500 sq. ft. in area, which is reasonably handy without large control forces, presents the smallest difficulty in handling. With the smaller scouts the essence of the pilot's difficulty is that his mental response is frequently not commensurate with their inherent quickness; with twin and multi-engined aeroplanes that his physical response to opportunities of control is too feeble. And in getting an aeroplane off, as much if not more than at other times, these characteristics assert themselves. To appreciate rightly the quickness of the aeroplane's motion and the magnitude of its control forces, is the first requisite of safe manœuvre close to the ground near stalling point.

(*b*) For many reasons both in war and peace the tendency to build comparatively heavily loaded aeroplanes is strong. Up to, say, 10lbs. per sq. ft., the loading should not introduce serious difficulties. Assuming equal power, the heavier the loading, the longer is the run to get off, and the greater the demand on the pilot's skill in handling. The stalling speed is increased, and the aeroplane has to be travelling faster over the ground before leaving it, so allowing a smaller margin for the correction of errors of judgment. When the more heavily loaded aeroplane has actually left the ground with a reasonable margin of speed, it undoubtedly feels steadier than the more lightly loaded one. But once the

loading rises to an unreasonable figure the control is seriously impaired; so that even under normal conditions with smooth ground and plenty of space the aeroplane becomes difficult to get off, and under severe conditions dangerous. If the loading is abnormally high, the large aeroplane is considerably worse to handle than the small one.

(*c*) The most notable, perhaps, of modern features in design is the greatly increased speed range of the aeroplane of to-day. This has in some measure been brought about by the increase in its aerodynamic efficiency, but more especially by the design of high power for weight aero engines. The influence of the possible speed range in getting off is of great importance. In the early aeroplanes which had barely enough power to maintain steady flight, when practically all the power the engine would give was used up in lifting the wheels clear of the ground, the acceleration was so gradual that the aeroplane ran over the ground for a long way bumping about in a degree of control that can best be described as questionable. Photographs of early aeroplanes getting off frequently show one wing dangerously dropped. Even when the aeroplane was off the ground, its height over the edge of the aerodrome was so small that the pilot was the whole time under the influence of the proximity of the ground. The saving condition of these aeroplanes was their extremely light loading. A heavily loaded under-powered aeroplane of medium size is worse; worse still is an under-powered heavily-loaded aeroplane of large size; which is what, in commercial aeroplanes, is most essentially to be avoided. The attainment in a flat calm of a definite height at a definite distance from rest with a good margin of speed and consequently of control should be rigidly insisted on, and this height and distance should be such that the pilot is quickly freed from the embarrassment of the ground; for safety, nothing ought to stand in the way of it.

Assuming that the engine were perfectly reliable and leaving out the question of economy, the relatively high-powered aeroplane, if not overloaded, is the safer in getting off. With the exception of intenser slipstream effects, the flying qualities near stalling seem to be improved; pilots sometimes describe such an aeroplane as "almost hanging on its propeller," in which saying there is some truth. With the under-powered aeroplane, the pilot is always tempted towards stalling in order to get off at all; and if partially stalled, he receives little assistance from his overburdened engine. Yet one thing to be remembered is this: if, in the high-powered aeroplane, the source of power does suddenly become extinct, the violence of the change of conditions corresponds with the power that is lost, and the pilot is left to contend with difficulties, not indeed so great as in the continual wrestling with an under-powered aeroplane when the engine is running, but greater than in the change of conditions if it fails.

(*d*) In most aeroplanes the pilot relies on the slipstream for a certain measure of longitudinal control during the first phase of getting off. That the pilot can do without, or very nearly do without its assistance is proved by the flying of some twin-engined aeroplanes. Most modern single-engined aeroplanes can be held tail down with engine full out at rest when the elevators are pulled up and the maximum negative incidence put on the adjustable tail; but there is certainly one that cannot. Nearly all twin-engined aeroplanes, on the other hand, would be pulled over on to their noses by the engines under such conditions; if the tail is not held down only one engine can be run up at a time. The position of the undercarriage relative to the C.G. and to the thrust line, the angle of the tail relative to the thrust line and wing chord, and the size of the tail plane and elevators must be allowed for, but the practice in modern aeroplanes is similar enough for the above generalisation to be made. It will readily be seen that if with throttle full open the tail can be held down at rest without artificial assistance, there will be no tendency for the aeroplane to tip over on to its nose in the first phase of getting off. On the other hand, if the tail cannot be held down, the pilot, before opening full out, has to be careful to allow the aeroplane to

gather a little speed, by which time the wheels will have started moving and the aerodynamic forces which enable him to exert longitudinal control will be coming into play. He will then have reached the second phase. In one or two twin-engined aeroplanes in particular, the pilot feels the tipping tendency in the first phase in a marked way.

In all single-engined aeroplanes, the slipstream, besides acting on the tail-plane and elevators, acts on the fin and rudder. In twin-engined aeroplanes also the fins and rudders are seldom uninfluenced. In getting off the rudder has frequently to be moved through its maximum angle, and its value as an organ of control is impressed on the pilot by the extent of its deterioration at low speeds. Although during the second phase the rudder control is gaining in effectiveness, not only is it necessary to cope with general disturbances, but is required to counteract a disturbing force which seems to attain its zenith during the second and the early part of the third phase of getting off; namely the effect of the rotating slipstream on the fin. If the propeller rotates anti-clockwise looked at from in front, there is a lateral force on the fin tending to turn the aeroplane to port; if the propeller rotates clockwise, the aeroplane tends to be turned to starboard. A similar turning tendency is also evident in twin-engined aeroplanes with propellers of the same sense of rotation. The onset of this disturbing force tends to be if anything more rapid than the corresponding increase in power of the rudder. To cope with this force the rudder has often to be used to its full extent, and is therefore of little use for counteracting the temporary and evanescent disturbances that co-exist with it. The above contentions are based on the assumption that the turning tendency is severe; at least they show that when an aeroplane is being designed, no effort should be spared to reduce the turning tendency as much as possible.

(*e*) I have said that in getting off, an appreciation of the flying qualities near stalling is of the greatest importance to the pilot. Nothing affects these qualities more than the character of the aeroplane's longitudinal and lateral stability.

In considering the stability of the aeroplane some sort of balance has to be assumed. Laterally the aeroplane is trimmed so that it is in balance with its wings parallel to the ground, although almost inevitably it will be out of trim when getting off due to the turning tendency caused by the slipstream on the fin. Longitudinally, the average pilot may be assumed to try to arrange the balance before starting so that the aeroplane will trim at its normal climbing speed. In the longitudinally stable aeroplane, as stalling speed is approached, there will be a couple tending to put the nose down; and the more stable the aeroplane is, the larger it will become. In the longitudinally unstable aeroplane which is in trim at some normal climbing speed, the tendency is for the aeroplane to put its nose up as stalling speed is approached; and, though of course it does appear ultimately, for the nose-diving couple to be longer delayed; general flying experience seems to indicate that the aeroplane can be partially stalled without its appearance, and that when it does appear it comes into play very violently and without warning. The stable aeroplane gives the pilot plenty of warning that it is going to put its nose down when near stalling; the unstable one is amenable to a stalling moment produced by the elevators; it seems to hang for a considerable period, until it suddenly dives. The delay in the automatic dropping of the nose allows time for lateral instability to develop in a more aggravated form, and the subsequent dive is frequently the first phase of a spin.

You may sometimes hear a pilot say, "I like to trim my aeroplane nose heavy for getting off," or another say, "I like to trim my aeroplane tail heavy for getting off," the idea presumably being that they would adjust the tail during the third phase of getting off so that the aeroplane would be in balance near its normal climbing speed. At first sight this discrepancy of opinion would seem to be without logical foundation, but there may be a reason for it. May it not be the pilot's instinctive provision for the behaviour of the aeroplane due to its

stability characteristics? The stable aeroplane is always trying to put its nose down near stalling, so the pilot wishes to make the aeroplane tail heavy getting off. The unstable aeroplane at its lower speeds tends to stall itself, and the pilot tries to arrange its unstable trimming speed so that throughout the major part of the speed range it feels nose heavy. He is thus subject to the smallest control forces.

(*f*) The paragraph dealing with slipstream effects was inevitably concerned with the control of the aeroplane. During the first phase of getting off, the pilot has to rely mainly on the action of the slipstream on the elevators, fin and rudder; or has to be extremely careful if he uses them unassisted by the slipstream. During the second phase he uses his control surfaces to maintain the aeroplane in the most suitable attitude to gather speed, in order to give them effectiveness; his skill in handling is here tested, as he may in addition have to encounter disturbing forces exterior to the forces normally encountered. During the third phase he handles the aeroplane so as to maintain it at or near its best climbing speed. This speed is frequently just so much greater than the lowest speed at which the aeroplane can fly as to give him a reasonable margin of control. If the air is very disturbed he may by selecting a slightly higher speed increase this margin, which should not however seriously affect his rate of climb; and as a disturbed state of the air is usually associated with a wind of some sort, his height over the edge of the aerodrome will not thereby be decreased. It is a definitely dangerous practice systematically to underestimate the margin of control referred to, as the pilot can never quite foresee the disturbing forces he may have to deal with.

Unless it is imperative that acceleration should be as rapid as possible, the pilot does not open his throttle or throttles with a rush, but usually occupies two or three seconds over it. This serves two purposes; firstly it lessens the risk of choking the engine, and secondly it gives the wheels a chance of moving before the engine is exerting its maximum force tending to pull over the nose. Especially is this necessary where the elevator is only affected by the slipstream to a small extent. Once the aeroplane is fairly moving and the air forces have begun to act on the tail, the pilot, by lifting up the tail skid so as to make acceleration as rapid as possible, enters on the second phase. Due to the low speed, he sometimes has to push the control stick full forward at this time. The aeroplane will then probably bounce owing to the inequalities of the ground. The most awkward time for a bounce to occur is at the commencement of the second phase, when the elevator is down fully to lift the tail, and there is no control left to put down the nose if the aeroplane is bounced up. But speed is gathered quickly, and further bouncing is less serious; in fact the entry on the third phase is far more frequently the result of a bounce than of the pilot's volition. After this point, the pilot should not be worried by his elevator control if the engine runs well.

On the whole, the difficulties of lateral control, *i.e.*, rudder and ailerons, are more serious at low speeds than those of longitudinal control, for lateral control is achieved by a delicate co-ordination of two organs, not by a direct use of one. A bounce at the beginning of the second phase is not infrequently accompanied by the dropping of a wing, the results of which, if the aeroplane is not head to wind, may be serious. The yawing moment due to the ailerons has also to be reckoned with, for which the pilot has to be on the watch until he is well into the third phase.

In single-seaters and smaller two-seaters that have been fitted with balanced rudders and relatively small fins, a feature has been evident that must be clearly distinguished from the turning tendency due to the slipstream. There have been cases where although at all speeds in flight down to stalling speed the rudder has felt normal and not overbalanced, the aeroplane has swung violently and indiscriminately from side to side when getting off, and to maintain a straight course energetic paddling with the rudder has been necessary. This feature has been

termed "woffling." No bite is felt on the rudder, and the behaviour can be compared to the feel of an abnormally small rudder actually in flight. "Woffling" has however occurred in aeroplanes with quite large, and apparently under other conditions not overbalanced, rudders. The rudder does not take charge of the pilot; the aeroplane simply swings; and in order to correct the swing, the pilot has, as it were, to anticipate the motion and use his rudder to the full lock. Watched from behind, the swinging of the aeroplane seems just out of phase with the rudder movements. An increase of fin area seems enough to damp out this tendency to "woffle."

(*g*) The general type of undercarriage to which pilots are accustomed is the plain "V" type, the shock absorbing properties of which are derived from elastic. There have been certain undercarriages of the "Oleo" type, and a few in which wheels have been employed in tandem.

One of the principal features with which the pilot appears to be concerned is the height of the undercarriage, which is mainly responsible for the angle of the aeroplane to the ground. No matter how safe is the aeroplane to handle in flight, it must be safe to handle in the first and second phases of getting off. Experience shows that the higher the undercarriage—with the consequent raising of the C.G. and thrust line—the more difficult is the aeroplane to handle. If the aeroplane tips over on to its nose the impact is worse, and it is more likely to fling itself right over on to its back. Auxiliary forward wheels, if capable of sustaining the whole weight of the aeroplane, may of course do much to mitigate this; but the fact remains that the difficulties of getting off previously enumerated are aggravated by a high undercarriage. The aeroplane as a structure is simply top heavy; and with a high undercarriage this is unpleasantly impressed on the pilot.

When getting off on an aeroplane with a high undercarriage the tail may be lifted a certain amount and the aeroplane may feel quite normal; if, however, before the second phase is well advanced the tail is lifted more than this, it tends to come up very easily and the power of the elevator to maintain the aeroplane at a reasonable attitude feels unpleasantly limited. If the elevators are being pulled back during the second phase to correct perhaps a slight error of judgment in allowing the tail to come up too far, the pilot feels that he has not enough control left to raise the wheels clear of the ground when the suitable time arrives. The effects of bouncing under these conditions are also aggravated.

During the second phase the pilot is partly under the influence of air forces, and partly under that of the ground. He feels the bite of the wheels on the ground, and from this he estimates to a large extent the time to begin the third phase. The ordinary elastic spring undercarriages, while acting as fairly efficient shock absorbers, give a reflection of what is happening as the wheels run over the ground, which the pilot feels. The "Oleo" types, with more efficient shock absorbing properties, scarcely give the pilot any ground feel. In getting off, this is in some ways a disadvantage, though in the larger more sluggish aeroplanes that do not drop a wing suddenly, the effect on the pilot is admittedly less serious. The question of how much various pilots rely on the ground feel when getting off is however a difficult one to answer.

(*h*) It has been advanced that a low undercarriage makes it easier for the pilot in getting off. Unfortunately the chief means of arranging the wings at a large angle to the ground is the high undercarriage. Most aeroplanes, with the exception of those with abnormally low undercarriages, have their wings somewhere near the critical angle when sitting on the ground; in one or two the angle may be slightly greater, in the neighbourhood of 17°. It does not appear that a large angle on the ground assists the pilot to get off, as he frequently raises his tail during the second phase so that the centre line of the aeroplane is nearly parallel with the ground. It is when landing that the large angle to the ground is of assistance.

When, due to a low undercarriage, the lower planes are close to the ground, a tendency for a nose-diving couple to appear while getting off has been noticed. This nose-diving couple may be due to a cushioning effect. If the aeroplane is trimmed so as to be in balance near its normal climbing speed, during the first and second phases of getting off it feels nose heavy, and tends to keep its wheels on the ground too long. In other words the pilot has to pull it off the ground to rise into the air. On the other hand if the aeroplane is trimmed so as to be comfortable getting off, then it will feel tail heavy in flight.

Apart from this, the low position of the wings seems to make getting off more pleasant, and, if only to a small extent, to damp bouncing.

(*i*) The position of the pilot in the aeroplane and the contour of the fairing round and in front of his cockpit influence his handling in a marked way. A subconscious view of the wings stimulates his sense of lateral balance; while his sense of longitudinal balance is normally derived from some feature of the aeroplane such as a top longeron of the fuselage. He may be seated in such a position as to be denied one or both of these; and although in practice he soon accustoms himself to do without them, when available he always makes use of them. If, after flying an aeroplane with a more or less horizontal fairing in front of him, a pilot gets into one with the fairing sloping steeply down to the engine cowling or the nose, he certainly feels lost at first, and cannot gauge accurately the attitude in which he is getting off.

There are few pilots who, for pure controlling power, would not prefer to be situated close to the C.G. The pilot then feels that physically as well as mentally he is the hub of the machine which he controls. Curiously enough, it is more doubtful whether for getting off this is the case. During the first and second phases the feel of the controls is of less use than at other times, and the instruments are of practically no use; if the pilot is at a little distance from the C.G. the consequent accelerations on his body are an additional guide as to his attitude, which he can well dispense with, and of which during ordinary flight he finds it more pleasant to be free.

2. General Notes on "Getting Off."

During the manœuvre of getting off, the influences discussed above are as a rule only felt subconsciously; the pilot is busy watching the ground, to which ultimately he refers all his actions. Though it is true that in night flying the pilot's sense of the ground is somewhat diffused, it is rare for him to take up an aeroplane at night on which he is not experienced by day.

When getting off, the pilot is really concerned with three things: his attitude, the horizontal component of his velocity relative to the ground, which he feels roughly as his air-speed, and the vertical component, which he feels as the rate he is leaving the ground. His sensory impressions are the chief clue to these three things; he refers his attitude to the plane of the ground and its perspective towards the horizon, the horizontal component to the ground moving past, the vertical component to the ground as it appears to drop away. During the third phase the feel of the controls, the feel of his seat, and the air-speed indicator are of some assistance. As the pilot accelerates in getting off, there is some mental lag in the progressive accommodation to new conditions, and he is liable to over-estimate his speed, that is, he is at any moment travelling more slowly than he thinks; it will be seen that in landing the reverse is the case; he is therefore more liable to stall when getting off.

In Part I., para. (2), I divided the process of getting off into three phases. The most favourable attitude for the aeroplane during the first and second phases should be that of least resistance; the air drag is increasing, and as the wings lift more, the friction of the wheels on the ground is decreasing. Whether

pilots do achieve the most favourable attitude by feel is an open question; at least they tend to keep the tail down on sticky ground when the ground friction is high. Pilots vary in their attitude during the first and second phases between keeping the tail skid nearly touching the ground and lifting it to such a height as will bring the fuselage parallel with the ground. Considering the angle that the wings are usually set to the fuselage, the latter attitude is never exceeded. On hard and uneven ground many pilots prefer to get off with the tail well down, as the aeroplane feels pleasanter when it is bumped about. This may be accounted for as follows. If the aeroplane bounces on rough ground with the tail well up, the tendency when the wheels strike the ground is for the aeroplane to nose over, and the angle of incidence to be decreased, thus decreasing the total lift just at a time when the pilot wants it increased. If, on the other hand, the tail is down, a similar bump will increase the incidence and consequently the lift, which certainly makes the aeroplane oscillate less violently. Of course, there is always a risk of this being overdone and lateral trouble developing, but the unpleasantness does not seem so great as that in bouncing with the tail too much up. Again, if the pilot gets bumped up to a large angle of incidence, he may not have enough control to put the nose down gently; instead of this, the nose-diving couple comes into play and the nose drops too violently, the wheels again strike the ground, and an increasing kind of oscillation is set up. The pilot must exercise his discretion both ways, and good style is the result of a happy compromise

The co-ordination of the rudder and ailerons has been referred to as worth the pilot's close study. The sort of difficulty which frequently arises is as follows. The pilot is in the second phase, and due either to an air disturbance or a bump in the ground, one wing is thrown up and the other is dropped. The pilot tries to pull up the wing by using his aileron, in which he may perhaps be successful. At the same time the aeroplane tends to yaw due to the effect of the ailerons at low speeds. This yaw he has to correct with his rudder; but if his rudder control is all but used up in counteracting the rapidly developing turning tendency (referred to in Part II., para (1) (*d*)) and the aeroplane is caused to yaw the same way as it is tending to be turned by the slipstream, the rudder may be inadequate to deal with the two effects added together.

It sometimes happens in flying that the pilot comes to the limit of his controlling powers before he has achieved what he wants; the only thing he can then do is to allow the aeroplane its own will and gently convert its motion into another manœuvre, which is the next best to that he desires to achieve; it is absolutely no use trying to use the controls in the vain hope of achieving the impossible, for in doing so serious elements of danger at once appear. Two examples of this can be given.

Take the case referred to in getting off. One wing has dropped. The pilot dare not attempt to raise it due to the rudder being inadequate to cope with the yawing moment produced by the ailerons added to the turning tendency. He simply has to allow the wing to remain down, very near the ground, and get off on one wheel, converting the motion, if he can accelerate the aeroplane sufficiently to lift the wheel off the ground, into a gentle climbing turn. The dropped wing will then give the correct bank for the turn. He will now in a natural and flowing manner have converted a straight get-off into a get-off with a gentle climbing turn, although he had, as it were, to change his mind in the middle of the second phase.

Again, suppose the pilot has got off with a steep climbing turn in order to avoid some obstacle. He has to watch his flying qualities carefully because due to the turn he will be much nearer stalling point. Then, owing to a slight error of judgment, he finds the aeroplane partially stalled at about 200 feet from the ground. The controls begin to fail him. What is his only method of recovery?

He must lose some of his precious height to regain a margin of speed and control, and he must lose it in the most economical way. He must let the aeroplane fall into a turn in continuation of the climbing turn, swinging round again towards his starting point, gently easing the nose down with as little control movement as possible. Were he to move any of the controls violently in this critical state he would stall, and the nose-diving couple would crash him nose on into the ground. The most frequent mistake is to try and straighten off the turn by moving the rudder violently against it and pushing the stick forward in an attempt to put the nose down. The pilot thinks that if he could get straight he would regain control. No idea is more fallacious, and as soon as he attempts to move the rudder across he stalls with a violent sideslip, and gets completely out of control. Aeroplanes which exhibit weather-cock instability more especially have to be handled with care in climbing turns off the ground. If the pilot is trying to avoid obstacles, or manœuvring for a good position as early as possible should his engine fail, a climbing turn falls into the category of forced manœuvres.

The effect of wind has not hitherto been considered. If the pilot is not restricted in any other way, of course he gets off up wind. If, however, he has to surmount a serious obstacle in getting off up wind, and there is a clear run down wind, he may select to risk a less pleasant get-off down wind for the sake of the clear run. It requires much more skill to get off across wind than up or down wind, due both to the difficulties of the aileron and rudder control and the incapacity of the under-carriage to stand up to lateral loads. Again, if there is a breeze blowing at 100 feet from the ground, the wind gradient in the neighbourhood of the ground seems usually quite steep, and luckily for the pilot the air within three or four feet of the ground is seldom disturbed. Especially does this appear to be so at night. If the pilot gets off up wind, the wind gradient helps him in the form of an additional insurance against stalling, because he gathers speed more quickly. Getting off down wind, it acts just as surely against him; therefore no pilot would think of getting off down more than a comparatively gentle wind, except on a relatively high-powered aeroplane.

Getting off across wind is a different matter. Again, it is only attempted with relatively high-powered or manœuvrable aeroplanes. The great thing is to curtail the first and second phases in order even at the risk of stalling to get the aeroplane clear of the ground as soon as possible, and then to drop the wing that is towards the wind, sideslipping into it, to keep a straight course over the ground. In fact, if it is practicable, the wing should be dropped during the second phase, and the get-off effected on one wheel; for if the risk of being blown right over is to be eliminated, the wind must not be allowed to get under one wing. When getting off across wind, lightly-loaded aeroplanes are the more difficult to handle during the second phase, due to the more violent effect of the wind; heavily-loaded aeroplanes during the third phase, due to the higher stalling point, and the temptation of the pilot to get them off at too low a speed.

3. "Getting Off" as a Forced Manœuvre.

This paragraph will deal with getting off under unnatural conditions. Suppose the pilot has to fly an aeroplane out of a small field surrounded equally by obstacles, he would naturally wish for a strong wind against which to get off; suppose again that the field is restricted on three sides and the wind is blowing from one of the sides adjacent to the open side, the obstacles on this side being too high for him to surmount, he has the choice of getting off either with a climbing turn, or if there is not enough room for this, towards the open side across wind. It should be noted that more frequently than the actual space of ground available before the wheels lift, it is the obstacles which surround it that worry the pilot, at least in English country.

Take the first case, where the pilot is compelled to surmount the obstacle. Unless it takes the form of steadily rising ground, the pilot would, during the third phase, hold the aeroplane down near the ground gathering as much speed as possible, and then, using up all the energy available to lift him clear, "zoom" as he approached the obstacle and allow himself to sink on the farther side. He could thus surmount a higher obstacle than if the third phase took the form of a steady climb. If, however, the condition at the farther side of the obstacle is to be that of steady climb, R. McKinnon Wood shows, in a theoretical analysis, that nothing is gained by the "zoom." Nevertheless, not only does a "zoom" enable the pilot to surmount a higher obstacle if he allows himself to sink on the farther side, but it means that during the period of the third phase, in which he is holding the aeroplane near to the ground, he will due to his speed have a greater margin of control in preparation for the final effort. If the pilot tries to surmount the obstacle by a steady climb, he is liable to attempt the climb at a very low air-speed, probably lower than his best climbing speed, under the impression that he is climbing faster due to the steep attitude of his aeroplane. In a steady climb at a low air-speed his control will be difficult throughout a sustained period, while in the "zoom" the period during which his control is reduced to a minimum is very short. In the kind of get-off just considered, the pilot naturally makes full use of any head wind there may be.

The second case, where in order to avoid the obstacle the pilot has either to get off with a climbing turn up wind or else straight and across wind, is a different one. The pilot's handling during the climbing turn and when getting off across wind have already been dealt with. If the wind is strong, the climbing turn would probably be preferred; if gentle, the get-off across it. A certain amount can be done to assist the get-off by holding back the aeroplane on the ground by artificial means while the pilot opens the engine full out, and then letting it go; but the pilot must be very sure of his powers of holding down the tail in the slipstream before he can practise this with safety (ref. Part II., para. (1) (*d*)).

If the surface on which the pilot has to get off is wet and sticky, he has to allow very much more time to get clear. As was stated before, he can only try to keep his tail down as much as possible, and never to get off on sticky ground down wind.

The last thing to be considered under getting off is engine failure. This must occur when the pilot is still under the influence of the ground, and from such engine failure more crashes result than from any other one cause. If the engine fails during the first or second phases, the aeroplane can nearly always be brought to rest by the pilot without damage of any consequence. In the third phase his situation is one of peculiar difficulty. When getting off, the pilot should always attempt so to manœuvre his aeroplane that should engine failure occur at any moment during the third phase, he will be able to effect a landing on reasonably good ground. With some aerodromes this is difficult; with many fields it is impossible. Nevertheless, it is an aim which should never be lost sight of, and in pursuance of which the climbing turn is particularly helpful. If there is a good piece of ground outside the aerodrome in the up-wind direction, the pilot should not fly directly towards and over it, for if his engine fails it may be hidden from view beneath his wings; he should manœuvre so as to be just on one side of it, so that he always keeps it in view until the completion of the third phase.

If the engine fails near the ground, the trim of the aeroplane may be violently upset, both longitudinally and laterally, and the pilot is bound to lose some height before he regains mental equilibrium and brings the aeroplane to a safe gliding attitude. The chief cause of crashes seems to be the desire of the pilot to turn back down wind in an attempt to land in the aerodrome which

he has just left. It is surprising how long it appears to take after climbing steeply with full engine to gain a margin of speed gliding, and how much it appears necessary to depress the nose of the aeroplane. And this must be attributed to the proximity of the ground. The pilot is tempted to commence his turn back before he has gained sufficient gliding speed, and so commences a spin at a low altitude from which there is no recovery. If he has not enough height—300 feet is about a minimum—it is imperative that he should glide on and make some sort of a landing even in very bad ground. It is better to approach bad ground with the power to flatten out than good ground without it. Another feature of the turn down wind is the way in which the apparent rate of travel of the ground up and down wind deceives the pilot. As he turns down wind he thinks he is going faster than he really is, which as it occurs on a turn, puts him, unless he takes the greatest care, in danger of stalling. It is far better to trust to the air-speed indicator reading than to watch the ground under these conditions, and make sure that the margin of speed really exists; for in gliding the stall develops so quickly after the controls first begin to feel sloppy, and the imminent approach of the ground appears so rapid, that the pilot has little chance to correct his error. His best plan, just as in the case of the "zoom," is to dive and gain as much speed as he can before approaching the ground; and rather than commence the turn at a dangerously low speed, carry it out with what speed he can gain during the dive.

The question of engine failure in getting off naturally leads up to a consideration of landing, and engine failure at the beginning of the third phase, when the wheels have just left the ground, will be discussed under that head.

PART III.—LANDING.

1. Factors which particularly influence "Landing."

As the factors to be discussed are mainly those which influence the flying qualities near stalling speed, most of them are common to the manœuvres of "Landing" and "Getting Off." As was stated in Part I., para. 2, the period of landing will be divided into two phases; the moment of contact with the ground terminates the first and introduces the second.

The factors which particularly influence landing may be enumerated as follows:—

(*a*) The absolute dimensions of the aeroplane.
(*b*) The loading.
(*c*) The stability characteristics and the balance of the aeroplane.
(*d*) The control surfaces and their effectiveness, especially at low speeds.
(*e*) The effect of the slipstream.
(*f*) The height, relative position and character of the undercarriage.
(*g*) The angle of the aeroplane to the ground with the tail down, and the height of the wings above the ground.
(*h*) The pilot's view of and his height from the ground, and his position relative to the C.G. and to the wings.

(*a*) Taking the four sizes of aeroplane considered in Part II., para. 1 (*a*), it may generally be stated that the twin-engined type is more difficult to marshal to the landing position, though simpler to land when correctly in position; that the scout and smaller single-engined two-seaters are easier to manœuvre for position, but actually more difficult to land. The very large aeroplane is seldom manœuvred at all, just simply flown in, using one group of engines to prolong the glide. The three phases of getting off require a steady effort of judgment the whole time, while although the approach to land does require nice judgment,

the chief effort during landing is more especially concentrated round the few critical moments when the aeroplane is just about to touch the ground. During these moments the timing of the stalled condition must be in complete harmony with the aeroplane's height above the ground, for the slightest error spoils a good landing and involves a disproportionately bad one. Though a bad landing may be saved by the use of engine, it is nevertheless a potential crash.

The larger types of aeroplane are as a whole easier to land because they are more sluggish and extend the critical period just before contact, so that the pilot has at least the chance of correcting small errors. On the other hand, the smaller aeroplane is more handy during the approach; natural drift can be quickly eliminated, or artificial drift introduced to meet abnormal conditions. If a large aeroplane is drifting near the ground, its sluggishness inhibits the quick removal of the drift. If the smaller aeroplane becomes partially stalled, speed may be regained in time to flatten out. The response of the larger aeroplane under these conditions is so slow that it is actually necessary in order to flatten out to get up a considerably higher speed than would normally be required.

(*b*) Most pilots have noticed the difference in the stall of an aeroplane when it is flown light, and then loaded up heavily. When light, the engine may be switched off and the nose gradually pulled up until the aeroplane sinks gently and puts its nose down again. Load the aeroplane up, however, carry out the same stalling operations, and the aeroplane will answer the elevators until suddenly it drops the nose, usually in conjunction with one wing, and feels as if it wants to spin. Furthermore, the stall occurs at a higher speed. There is a double reason for precluding such slow safe flight; the stall occurs sooner, and the flying qualities associated with it are worse.

As in getting off, the large heavily-loaded aeroplane is worse to handle than the small one. With the small racing scout loaded to an abnormally high figure, the pilot takes his own risk about landing; but as long as landing is purely an effort of judgment, safety on the larger commercial aeroplanes must demand a low landing speed. The tendency is therefore to search for wings whose form may be varied in flight in order to increase the speed range of the heavily-loaded commercial aeroplane by giving an absolutely safe landing speed while retaining a reasonable top speed. Whether the speed range be increased by relatively high power with a fixed wing section and a high landing speed or by variable camber wings and a reduction of the landing speed, there is a definite effect produced on the pilot. If he flies an aeroplane with a big speed range and attempts to land at, say, a third of the speed at which he has been flying, he has, due to the lag of his senses in accommodating themselves to the new conditions, the feeling that he cannot reduce his speed to what appears to him a ridiculously low figure; he feels that he must be stalling, and consequently tends to come in to the aerodrome too fast. With a big speed range it is really difficult to make use of the very lowest speeds that may be safely possible. The pilot is always going faster than he thinks. This effect is particularly noticeable if high speed aeroplanes are watched coming in after a race. They nearly always, allowing for the high loading, tend to come in unreasonably fast because of the pilot's difficulty in adjusting himself. Motorists experience this when a ten-mile limit is approached after motoring fast on the open road.

(*c*) The longitudinally unstable aeroplane is more difficult during the earlier part of the first phase of landing, the stable aeroplane more difficult actually to land. Taking into account what was said about relative size, the large unstable aeroplane is to be avoided at all costs. When in the first phase the pilot is approaching to land the unstable aeroplane, he has to maintain it at the correct speed, and is more likely to be deceived into stalling, especially on a

turn; the stable aeroplane, if the tail adjustment admits, and it should admit, can be made to assume a natural gliding speed without trouble, to which it always tends to return.

It will be seen that an unstable aeroplane, although near stalling its instability tends to be reduced, really tends to land itself. The wheels and tail-skid will have probably made contact with the ground before the nose-diving couple is felt. If the unstable trimming speed is arranged to coincide with or slightly exceed the desired speed of glide, the pilot has only to release the control stick at the right moment and the aeroplane will naturally stall itself gently on to the ground; in any case, with very little effort the pilot can gently check or assist the motion to bring about a favourable conclusion.

If the aeroplane is stable and is set to trim at the desired speed of glide, the stalling moment of the elevators will be progressively opposed by the effect of longitudinal stability, until just before contact with the ground the nose-diving couple requires the full upward movement of the elevator to counteract it. The movement of the control stick to flatten out begins gently and ends in a comparatively violent pull right back that must be perfectly timed; if it is made a moment too soon, the control is all used up and the nose-diving couple bangs the wheels on the ground. The onset of the nose-diving couple may be in some measure postponed by arranging the trimming speed to be slower than the desired speed of glide, that is, making the aeroplane feel slightly tail-heavy gliding; but this always introduces the tendency to stall during the earlier part of the first phase.

Unlike longitudinal instability, lateral instability does nothing but increase the pilot's difficulties. Dihedral certainly postpones the dropping of one wing, and aeroplanes with no dihedral drop one wing very quickly and land hard on one wheel if not stalled directly on to the ground. But practically all aeroplanes show this tendency to some degree, which is just what the aeroplane, as a structure, will not stand. The drop that an aeroplane will stand up to on one wheel is insignificant compared to the drop on both wheels equally; and it is nearly always heavily-loaded aeroplanes that upset the pilot by suddenly dropping a wing.

(*d*) Professor B. M. Jones has said that a truer criterion of the landing difficulty than the stalling speed is the slowest safe speed of manœuvre near the ground, and suggests that although in general the margin of speed necessary with different types is at present of the same order, this margin could be materially reduced if the control near stalling could be improved. I think that it is on the confidence that the flying qualities near stalling give to the pilot that he bases his judgment of the lowest safe speed. In most aeroplanes the lateral trouble develops first; and if the aeroplane, though highly controllable longitudinally at low speeds, is vicious laterally, the extra longitudinal control will avail the pilot practically nothing. It is essential that if the flying qualities near stalling are to be improved the lateral and longitudinal be kept on a par; and in present-day aeroplanes the lateral element needs improving to bring it up to the longitudinal.

A feature that tends to mar the longitudinal control is a large difference of trim with engine on and off. Not only should the range of the adjustable tail be amply sufficient to cope with this, but the difference should be reduced as much as possible to make the necessity of a large tail range remote. The pilot does not want to be hampered in making full use of his primary organ of longitudinal control, the elevator, by compulsory attention to his secondary organ, the adjustable tail plane. Especially does this hold should he be compelled to make use of his engine suddenly to save a bad landing. He has no time or energy to concentrate on anything but the simplest control mechanism when he is in close approach to the ground.

During the war a form of air brake was fitted to a service aeroplane with the idea of increasing the gliding angle and pulling the aeroplane up on the ground. H. Glauert has pointed out in R. & M. 667 that the speed drops so rapidly in the run along the ground as to render such brakes of little use. The increase of gliding angle certainly does assist the pilot to get into a confined space over obstacles, but a distinct danger arises from the fact that the pilot is likely to bring his air brakes into action while coming in without realising what his change of gliding angle means. To glide in at the same speed he must keep his angle of incidence the same, and so must rotate the body of the aeroplane through the change in gliding angle. Because he suddenly glides steeper the idea is presented that he is going correspondingly faster, and on this assumption he may commence manœuvres which he would not otherwise attempt. It is always a question whether it is wise for the pilot to change the characteristics of his aeroplane when under the influence of the ground.

In getting off, with the point at which he leaves the ground as his starting point, the pilot has, within fairly wide limits, freedom as to his subsequent direction; his lateral control is mainly necessary for counteracting casual disturbances and only in a wide sense for voluntary manœuvre. In landing, on the other hand, his manœuvres are executed with the express purpose of arriving at a definite point; and, if he is unwilling to face judging a long straight glide or relying on his engine, they may be termed compulsory, almost involuntary, manœuvres. His lateral control is then more important still, for it has to be utilised to counteract disturbances simultaneously with the execution of low-speed manœuvres. Although the aileron control has not been found in practice to reverse, the yawing moment due to the ailerons is more noticeable even than in getting off, probably owing to the small slipstream effect on the rudder. Some pilots actually appear to utilise the yawing moment to assist manœuvres for losing height at the edge of the aerodrome, but unless the pilot is experienced, considerable risk is involved.

The rudder control suffers badly at low speeds, for if the rudder is made small enough to be reasonably light at high speeds, it is usually overpowered by the ailerons near stalling. This may be, and is, partly overcome by the use of balanced rudders, but the balancing itself, if carried out to any extent, introduces other difficulties.

Some aeroplanes, especially those without steerable tail-skids, show a tendency to spin round on the ground during the second phase, and the rudder is not sufficiently effective to prevent this spin. The pilot might give the rudder more power by a burst of engine and the subsequent slipstream effect; but he is often unwilling to increase the speed at which he is running along when on a turn. In any case it is unwise to check the turn too violently; the aeroplane should be allowed to go on turning until nearly all speed is lost before risking a burst of engine.

(*e*) It is not always sufficiently realised how different an aeroplane feels when the engine is throttled down for gliding and when it is completely switched off. The pilot relies more than he knows on this slipstream effect, small as it is, to assist his rudder. If his engine fails completely, and he has not tried flying the particular type of aeroplane with no engine at all, he frequently experiences a feeling of helplessness for a few moments until he has accommodated himself to the new conditions. The rudder control of many aeroplanes at low speeds without any slipstream is by no means satisfactory, neither are these difficulties imaginary.

When carrying out manœuvres for losing height at the edge of the aerodrome, the pilot finds an occasional burst of engine of the greatest use to assist his control. These bursts of engine are not always given, as is often supposed, to

prolong the glide. As has been stated before, the secret of manœuvring at low speeds is the co-ordination of the rudder and ailerons; lack of co-ordination means a loss of height, and more important, of direction, before the error can be corrected. The pilot is thus hindered in his attempt to arrive at the desired landing point. When the rudder and ailerons are not co-ordinated properly, the aeroplane, if on a turn, seems to stick, or its motion becomes jerky. A burst of engine, especially in a large aeroplane, will often relieve this condition at once by assisting the rudder.

(*f*) If the undercarriage is high, the pilot feels that his aeroplane as a structure is top heavy during the second phase of landing. If for a moment the value of a large angle of the wings to the ground is set aside, the pilot always feels safer if the vertical distance from the wheel axis to the C.G. and to the line of thrust is kept to a minimum, because the overturning tendency is thereby reduced. He further realises that if he does go over, the impact will be much less severe.

The necessity of ground feel, advocated for getting off, is of no importance in landing, probably because the conditions of the second phase of getting off are generally avoided. In landing, the aeroplane is either definitely air borne or running along with its tail-skid on the ground. In getting off it was noticed that an Oleo type of undercarriage tended to eliminate the ground feel which was of value to the pilot, whereas in landing this is of no moment, and excellent shock-absorbing properties are essential to preserve the structure from damage.

One of the worst features of the present-day undercarriage is its incapacity to stand up to lateral loads. The pilot has always to concentrate on eliminating drift prior to contact with the ground. This, due to the bad rudder control at low speeds, is often difficult to achieve. Consequently a large proportion of minor crashes are due to landing with drift and the subsequent collapse of the undercarriage.

In the simple "V" type of undercarriage, the wheel position, which even now is quite a delicate matter to determine, is of the greatest importance. It usually has to be settled by practical trial. If the wheels are too far back, the overturning moment may be more than the controlling moment of the elevators with the reduced slipstream, especially if the aeroplane bounces in landing. If the wheels are too far forward, the aeroplane is inclined to "bucket" and an oscillation is set up, which if not taken in hand by the pilot and damped at an early stage, may also result in the aeroplane turning over. If the aeroplane starts to "bucket" the tail-skid receives severe shocks. The only advantage of wheels placed far forward is that landing on soft ground is made easier. The advantage to the pilot of such a wheel position can be reproduced on commercial aeroplanes where the maximum reduction of weight and resistance is not so essential as in war aeroplanes, by wheels placed in tandem. If ground brakes are employed, and it seems likely that they will be necessary in future, tandem wheels are essential. H. Glauert points out in R. & M. 667 that if ground brakes are employed a reduction of the run is only effected by increasing the angle of the wings to the ground above the critical angle. If the increase of angle is within limits below the critical angle, the run is not sensibly shortened.

Especially on large aeroplanes a wide wheel track is of great advantage in steadying them if they are not landed with the wings level. One small scout at least has been successfully fitted with a wide track undercarriage. Although this aeroplane is inclined to oscillate sideways due to uneven ground, it lands well and safely, and has less tendency to spin round on the ground after landing. On single-engined aeroplanes built for war purposes, the undercarriage has usually been fitted to the fuselage unit, which has more or less settled the width of the track. For commercial aeroplanes a wide track should make them on the whole easier and safer to land.

The pilot can make a safer landing on soft ground by having his tyres fairly soft so as to widen the effective tread.

To sum up, it is suggested that the vertical distance from the wheel axis to the C.G. and thrust line should be kept to a minimum; that undercarriages should be made capable of absorbing side shocks to a much greater extent; that the desirability of good shock-absorbing properties is in no way lessened by a necessity for ground feel in landing; and that on commercial aeroplanes tandem wheels combined with the widest wheel track possible will make for safety and ease of landing.

(*g*) The low undercarriage, although it may reduce the angle of the wings to the ground, tends to bring them closer to it. H. Glauert in R. & M. 667 does not seem to attach much importance to the effect of a low wing position, at any rate, for reducing the run. It has been a matter of flying experience, however, that certain aeroplanes whose lower planes were close to the ground, within half a chord, were notably easy to land. The wings definitely felt as if they cushioned against the ground and the aeroplane did not appear to drop a wing so easily. This may have been in some part due to the fact that the proximity of the wing to the ground made it easier for the pilot to judge his height prior to contact; but the fact remains that it was a widely expressed opinion. The couple tending to put the nose down due to cushioning has not, as in getting off, been sensibly noticed by pilots. A large angle of the wings to the ground undoubtedly does reduce the run of the aeroplane, but in landing the pilot feels it more difficult to get his tail down, neither is his position so comfortable, as the nose tends to rise up in front of him and block the view ahead.

(*h*) It is naturally essential for the pilot to have a good view during both phases of landing—as he is gliding down in the approach, as he makes contact, and during the subsequent run. As he approaches, he must be able to see if the landing space ahead is clear, or otherwise he is timid and uncertain in his preliminary manœuvres. When he is about to make contact with the ground, it is unwise to try and gauge the height of the aeroplane from the ground by looking down steeply over the side, and worse still to look back at portions of the aeroplane such as the wheels, even should they be visible. Among other things, his sense of lateral balance is certain to be upset. He should look at the ground about fifty yards ahead, at which distance it does not appear to be moving very rapidly, relate its appearance to the general perspective of objects towards the horizon, and thus judge his attitude relative to the ground. If he looks down at the ground rushing past near to him, its apparently rapid movement tends to unbalance his judgment.

In a few aeroplanes, while the view downwards is good, the view forwards is restricted too much by the spar of the top plane being brought too near the level of the eyes—with the object of allowing the pilot to look over it. For landing, he is compelled to look downwards rather than forwards and his judgment is interfered with.

Although experienced night-flying pilots can land at night with little or no illumination, the average pilot needs a set of flares, unless he lands down the beam of a strong searchlight. He has to concentrate not on where he supposes the ground to be, but on the perspective of the flares; when they become nearly superimposed he flattens out.

Within limits the pilot accommodates himself easily to landing large aeroplanes in which his seat is a large vertical distance from the ground. Experience seems to indicate that the lower the pilot is, the easier it is for him to land; but it has not proved how high the pilot can be seated without encountering real difficulty.

Provided the pilot is not at an abnormal distance from the C.G., for landing the position of his seat does not appear to affect him much. If he sits behind the planes, the consciousness of them assists his judgment; on the other hand, his view is so much better if he sits in front that by losing the first advantage he gains the second. It is, however, always helpful to have some sort of fairing in front of him which will assist his idea of the attitude of the aeroplane.

2. General Notes on Landing.

In the earlier days of flying the modern "tail down" landing was seldom, if ever, practised. The aeroplane was glided down, and in the case of such scouts as then existed, at an excessive speed for fear of stalling; after which the pilot attempted to run along the ground with the tail up, allowing it gradually to sink down as the aeroplane slowed up. Such landings were nearly always associated with violent bounces, due to uneven ground, and corresponding risk of damage. War conditions forced the pilot to change his attitude. If aeroplanes were to be landed on soft or rough ground in confined spaces, the problem of landing would have to be more finely appreciated. And it was. Consequently the practice was made of getting the tail right down before making contact with the ground, and was not after all found so risky as had been supposed. The risk of dropping a wing, as time went on, was further diminished by better design.

Supposing for the moment that the pilot makes a straight approach to the landing space, he may have some latitude both in the line of his flight and in a lateral direction as to where he may safely make contact so that his subsequent run may be all on good ground. But when, travelling at a minimum of 60 m.p.h., he views the landing space from the air, it looks surprisingly small and gives him an unpleasant sensation of constraint. If the latitude as to where he may touch the ground in the line of his flight is 300 yards, the maximum period he will have in which to make up his mind is roughly 10 seconds, after which time he will have overshot his mark; or alternatively, assuming a gliding angle of 1 in 6, he must judge his height over an obstacle within 150ft. The flatter the gliding angle of his aeroplane, the more will this margin contract. As a matter of fact, the pilot very seldom attempts to judge a straight up-wind glide; he approaches the landing space with a margin of height, and loses it by a series of manœuvres which will be discussed later.

Associated with the tail up landing practised in earlier days was a kind of rapid flattening out. The aeroplane was glided down and, until it was within a few feet of the ground, flattening out was postponed, and was correspondingly violent. The pilot then allowed the wheels to touch and so ran along until the aeroplane came to rest. This kind of flattening out, however, can be made in conjunction with a tail down landing, which means that the pilot keeps the aeroplane near to the ground without making contact until it stalls. The greater the speed at the time of flattening out, the longer the period before contact with the ground. This holding the aeroplane near to the ground is a severe tax on the pilot's mental concentration, as the flying qualities change with the loss of speed and the controls require the most delicate handling. If the pilot becomes fatigued, he lets the aeroplane either touch the ground too soon or curve up into the air again and stall too high.

Most pilots therefore try to diminish the period close to the ground by commencing to flatten out at from 20ft. to 30ft. up, thus approaching the ground more gradually. If the pilot could foretell the precise moment at which the aeroplane was in a suitable condition for contact with the ground, he need never consciously hold the aeroplane near to it; in practice he dare not risk such an accurate forecast, and always tries to allow at least a small period to elapse while he holds the aeroplane very close to the ground, awaiting the final condition of stalling. Pilots often refer to this as "flying the aeroplane right out." In forced landings the pilot may elect to bring the aeroplane in so slow and right on

the edge of his controlling powers, that the period referred to becomes sensibly zero. But should his judgment be in the slightest degree out, a crash is inevitable, especially as he may have no engine to accelerate him at the last moment.

The normal gradual flattening out may actually be associated with a manœuvre such as turning or side-slipping, by which it is apparently masked; but the pilot must so arrange the manœuvre that a form of flattening out is really inherent in it.

In landing, as in getting off, the pilot is concerned with three things: his attitude, the horizontal component of his velocity relative to the ground, and the vertical component; the relative magnitude of which two components determines his gliding angle. The pilot arrives at a point from 20ft. to 30ft. above the ground, gliding at some speed at which he has a reasonable margin of control. From this point his path becomes curved; at any moment the lift of the aeroplane is just greater than the weight, and immediately prior to contact with the ground, the vertical component of his velocity should be reduced for a perfect landing nearly to zero. Now, neglecting the effect of the propeller, there are two factors which influence the control movement necessary to produce the required path. Firstly, the stalling moment necessary to be produced by the elevators; and secondly, the negative acceleration at any moment during the time that the attitude of the aeroplane is changing; for as the speed drops, the resistance at any moment changes. At some moment prior to stalling, the aeroplane may pass through an attitude of minimum resistance. This attitude, on the other hand, may be that corresponding to the speed at which the aeroplane is gliding when the flattening out commences; in most cases it is probably in the neighbourhood of this speed.

Suppose that the aeroplane is initially gliding at its best gliding angle, that is, with minimum resistance; and suppose the speed which corresponds to this is 60 m.p.h. The subsequent curvature of its path will be associated with the alteration of its attitude and its corresponding loss of speed, the whole being made to culminate in the desired conditions just prior to contact with the ground. The pilot, by the use of his elevators, has to ensure that speed is gradually and steadily diminished throughout the curved path, and this dictates his attitude. Immediately the pilot commences to flatten out the aeroplane, which is assumed to be gliding at its best angle at 60 m.p.h., he will drop the speed. But at this lower speed the resistance will increase, and progressively so towards stalling. So to produce the curvature of path that he desires, the speed must decrease more and more rapidly as the ground is approached, and the attitude of the aeroplane must be altered to correspond, or the pilot will fly into the ground. The pilot does allow for it by a progressively more decided use of the elevators. As it happens, he has to use his elevators more decidedly as the speed drops, for two reasons: firstly, for the one mentioned, and secondly, because as the speed drops the control becomes increasingly less effective. It is, of course, by his sense of the rate of approach of the ground that the pilot allows for all these somewhat complex effects. It is emphasised here that the progression is all towards using the control more decidedly as the stall is approached.

But now suppose that the pilot, possibly for fear of stalling the aeroplane because he is being bumped about on a rough day, glides the same aeroplane in at 75 m.p.h. The resistance at 75 m.p.h. is greater than at 60 m.p.h.; so if his path is straight, the vertical component of his velocity is greater. When he commences to curve his path, the approach towards the attitude of minimum resistance requires a progressively less vigorous control movement to flatten the aeroplane out relatively to the ground; but there will come a critical time when the attitude of minimum resistance is passed and it becomes steadily greater. It is here that the pilot is likely to be deceived. The fall of resistance and the sensitiveness of the control at the higher speed, at first seemed to stave off the approach of the ground with a negligible effort on his part. After the critical

point, he suddenly finds himself into the ground with a violent bounce, because he has not allowed for the more rapid decrease of speed. It is suggested that the above may be an explanation of why the pilot so often tends to fly into the ground if he glides in fast, that is, at a speed greater than that which corresponds to the attitude of minimum resistance or best gliding angle. On the other hand, the effects described above are probably masked in many cases by the stability characteristics of the aeroplane.

Whether the pilot curves his path gradually over a long period, or suddenly over a short one, the above remarks apply in the main. The advantage of not having to hold the aeroplane close to the ground for a protracted period, while it "flies itself out," is seen to be that the consequence of a slight error in the allowance for the change of the vertical component of the aeroplane's velocity is not so likely to be followed by a violent bounce. More times than not, a pilot involuntarily performs the high-speed rapid flattening out type of landing through an ungovernable shrinking from a reduction of speed, especially when the air is disturbed. In reality the type in which he gradually flattens out is his ideal of good style. As in all flying, violent control movements, unless dictated by imperative conditions, are the result of subconscious timidity or uncertainty of the pilot.

H. Glauert states in R. & M. 667 that a reversible airscrew would be of the greatest assistance in reducing the space required for landing. As long as the success of a landing is so intimately bound up with an exquisite kind of judgment, it would be difficult for the pilot to operate any kind of auxiliary control once he came under the influence of the ground, however useful it might prove in reducing the landing space. H. Glauert further points out that a reversible airscrew would not be available in the case of a forced landing without engine. It might be added that the pilot would be precluded from using his engine to increase the curvature of his path, should he need it at a critical moment.

If there is a wind, the pilot always lands against it. Just as the wind gradient near the ground assisted him in getting off, it disturbs him in landing. If the pilot lands against a strong head wind, he often, as he approaches the ground, feels himself unaccountably dropping. This must in many cases mean that he tends to lose speed without realising it, due to the drop in the velocity of the wind near ground level. With the exception of this effect, there is nothing to fear from landing into a strong wind, as the actual speed of the wheels relative to the ground when contact is made is very low, and the subsequent run correspondingly short. It is a curious fact that when landing into a strong wind pilots so frequently tend to make contact with the ground with the tail up. This must be because they feel themselves travelling so much more slowly relatively to the ground that they are led into believing that stalling speed has been reached and that the aeroplane is ready for contact with the ground.

Although it has been pointed out that the pilot nearly always loses height near the edge of the aerodrome by manœuvring as a matter of course, these manœuvres will be considered in the paragraph dealing with forced landings, in which they are the decisive factor. Landing across wind, although sometimes deliberately practised, will be dealt with in a similar way. Landing down wind is not considered, as a modern aeroplane cannot be landed down a wind of any strength without the most severe risk of a crash. Furthermore, there seem to be no particular methods by which the pilot can diminish this risk.

3. "Landing" as a Forced Manœuvre.

Engine failure in the air means a forced landing, which, as has been stated before, is usually taken as the ultimate test of the pilot's skill and judgment. Sometimes the pilot is able to avail himself of a small amount of engine, which, though it will not enable him to climb up and try a second landing should he

misjudge at the first attempt, serves to prolong his glide. The breakage of any essential part of the engine usually means switching it off altogether. If such a breakage occurs on a twin-engined aeroplane, unless the pilot can stop the propeller of the damaged engine, he will probably find it necessary to glide down as quickly as possible owing to the liability of very severe vibration being set up and the consequent menace to the aeroplane structure.

As in getting off, it is usually the obstacles which surround possible landing spaces that constitute the difficulty; so, especially if the gliding angle is flat, the pilot must, if for no other reason, have recourse to manœuvres to bring the aeroplane to the ground as soon after the obstacles as possible.

Engine failure may occur either at the beginning of the third phase of getting off, when the wheels have just left the ground, or towards the end of the third phase; or when the pilot is well up and free from the influence of the ground. In the first case the pilot is compelled to effect a landing immediately in his projected line of flight, trusting that he will not overrun the limits of good ground before coming to rest. Landing under these circumstances is difficult to execute without very severe bouncing and consequent risk of damage. The pilot finds himself somewhere near his best climbing speed, close to the ground, with the slipstream effects suddenly eliminated. Depending on how close he is to the ground, there are two courses open to him. If he is only 3ft. to 6ft. up, he may, without moving his longitudinal control, allow the aeroplane to sink on to the ground, due to loss of engine power, and trust that it will make contact more or less in stalling attitude. If, however, he is 20ft. to 30ft. up, he may attempt to put the nose down and induce a kind of glide from which he may hope to flatten out in the usual way. He must remember that the aeroplane will be sluggish in answering to the longitudinal control, that after engine failure it will begin to sink rapidly, and that if it answers sluggishly to the longitudinal control and only starts putting its nose down as it approaches the ground, there is no hope of flattening out; it were better that the pilot had attempted to keep flat from the moment of engine failure and trusted that the stalling moment of the elevators would be sufficient to hold in check the nose-diving couple until the wheels touched. Just whether or not the pilot will decide to put his nose down when the engine fails close to the ground is a critical test of his judgment.

If the engine fails towards the end of the third phase of getting off, the pilot has to choose between going straight on or attempting a backward turn. This has been discussed in Part II., para. (3). It was noted that if the pilot does elect to turn back, it is safer to dive and gain speed before commencing the turn than to commence the turn and try to gain speed while turning. It was a part of the teaching of the Gosport School of Special Flying, which initiated the modern conception of aerial manœuvre, that if the engine failed and the pilot judged that he could turn back, it was safest for him to dive down and carry out the banked turn with his inner wing tip close to the ground. If then at any moment his available margin of speed disappeared, he could effect a landing without the risk of a nose dive.

Lastly, if the engine fails when the pilot is well up, the first phase of landing may be said to commence when he puts the nose down and commences to glide. From this moment he manœuvres for position by gliding towards the most open-looking stretch of country. On the whole it is not worth while, except in a very wide sense, selecting a landing place from above 5,000ft., as local features are too obscure; and once the pilot has committed himself to the idea of landing in one place, it is disturbing to be compelled to change his mind later on. If possible, the pilot should attempt to arrange his glide so that he will pass over the selected landing place at an altitude not exceeding 2,000ft., to enable him to make one good inspection. This he can do by gliding over it down wind. After that the general idea will be to approach the landing space with a margin of height to avoid the risk of undershooting, and lose this height by manœuvre.

Every pilot has some particular way of manœuvring to lose height that he considers safest and most efficacious.

The simplest way, if the field has breadth at right angles to the wind direction, is to make use of this breadth by approaching the field just short of one edge at right angles to the wind. The pilot has then a certain latitude of time in which he can turn up wind, during which time he is losing height and is yet within range of the landing space. He can further assist his rate of losing height before turning up wind by sideslipping in the down wind direction. The wing farthest from the landing space will then be depressed, and the turn up wind will help him off the sideslip, as in itself it ensures the lifting of the depressed wing in order to bank for the turn.

A method of losing height that was in greater vogue formerly than to-day was to approach the landing space with a margin of height and then lose it by a series of partial turns, first one way and then the other, usually termed S-turns. This method enables the pilot to lose height quickly, but it has disadvantages. Firstly, by the complication of the manœuvre, the pilot tends to become confused in his sense of direction; and secondly, it is difficult to execute turns with the engine off without unconsciously increasing the speed, due perhaps to the pilot's instinctive fear of lateral instability at low speeds.

A modification of this method gives a still more rapid method of losing height. Instead of carrying out properly banked S-turns, the pilot does flat turns, yawing the aeroplane violently from side to side, up to as much as 60 or 70 degrees from his line of glide. For each flat turn he gives a turning impulse with the rudder and uses the ailerons against instead of with it, allowing the yawing moment due to the ailerons to increase the flat turn; which virtually amounts to letting the aeroplane take charge and then recovering. The aeroplane loses height with surprising rapidity, but the margin of control is too small for anyone but an extremely skilled pilot to practise this manœuvre.

A method which has the advantage of being a steady even manœuvre is the "sideslip" landing. It commends itself as being effective, reasonably safe and not liable to confuse the pilot, who simply puts one wing down and maintains a steady sideslip, varying the steepness according to the rapidity with which he wishes to lose height. It is an advantage if he allows the aeroplane to slew slightly, so that as he glides down the depressed wing is forward of the raised wing; for the nose of the aeroplane is then not in front of his eyes as he looks down at the place he intends to land on, and allows him a particularly good view. When the aeroplane approaches the ground the pilot straightens it out and effects a landing in the ordinary way. A perfectly clean recovery from such a sideslip is not unattended with difficulty, and the pilot may find himself drifting sideways, due to imperfect co-ordination of his controls. Most undercarriages will not stand up to lateral loads of any magnitude, and it is peculiarly important that the pilot should make contact with the ground without drift. As a last resource, the pilot can drop one wing, thus causing sideslip the opposite way in order to neutralise the drift. If he does this with skill, he will effect a landing on one wheel without damage. After running a few yards, the aeroplane will sink down on its other wheel and come to rest in the normal way.

The above methods of approach have been detailed separately; the actual practice of pilots is very difficult to analyse; the way in which an experienced pilot loses height is frequently a combination of features peculiar to these methods that is influenced by local conditions, because every forced landing in a confined space surrounded by obstacles is a different problem.

The pilot may sometimes be compelled to land across wind if the landing space is narrow and the wind is blowing across it. He therefore finds himself drifting badly as he approaches the ground. The most effective way of neutra-

lising this is by the method referred to, *i.e.*, dropping a wing and landing on one wheel. There is still another method, which consists in putting on full rudder at the last moment before contact and inducing a flat turn towards the down wind direction, which has the effect of causing the aeroplane to skid sideways in the up wind direction and of tending to neutralise the drift. Owing, however, to the uncertain action of the rudder at such a low speed, this method is generally less effective than the previous one. Neither method, of course, is resorted to unless it seems likely that the undercarriage will collapse sideways if the drift is not neutralised.

On lightly loaded aeroplanes it is sometimes possible to make a very slow landing by producing a sideways skid close to the ground with the rudder and making a recovery just before contact, but on heavily loaded ones it is almost impossible.

If the pilot finds that he is running into bad ground towards the end of the second phase of landing, he attempts to spin the aeroplane round on the ground with the last of his rudder control. An emergency device on the tail skid, in the form of a sprag, might be of use under these conditions. Its braking action could be made so severe that the ground would be torn up and the rear of the fuselage possibly damaged. It would never be used under normal circumstances, but it might be useful in preventing the aeroplane colliding with an obstacle at the last moment, or turning over on its back in bad ground at the end of its run.

Should the pilot be compelled to land on undulating ground, a comparatively steep uphill gradient is easier to land on than even a gentle downhill one, unless the aeroplane has efficient wheel brakes. In order to land uphill, the pilot must leave himself a greater margin of speed with which to flatten out; the actual flattening out will also have to be of a violent nature.

In making a forced landing without engine from a great height the pilot's difficulties of judging the landing are increased. As he glides down he thinks in terms of thousands of feet, and, if he has no chance of flying round for a short time low down, he finds it difficult to think in terms of inches, just prior to contact. If he misjudges his glide he may have to pass over obstacles at a dangerously low speed, and as he finally approaches the ground he will find that the vertical component of his velocity is very large. The best thing for him to do is to concentrate the whole of his flattening out in a violent jerk at the last moment, using his elevator control to the full extent rather than attempt a gradual flattening out. Similarly, if he is compelled to glide at a very low speed to reach the safe landing place, he must practise the greatest economy with his control movements; the slightest unnecessary control movement means loss of height which he cannot afford when he is trying to eke out to the uttermost his last disappearing margin of control.

Finally, if the pilot is compelled to approach ground on the surface of which it is impossible to make a landing in the accepted sense of the word, he will do best to keep a good margin of speed and control until the last moment, when he can expend this by pulling the nose up with a violent jerk, trusting that he will drop flat before the nose-diving couple comes into play. If he remains sufficiently cool, it should be possible for a pilot, by keeping his speed till the last moment and then jerking the aeroplane up on its tail, to place it on the sloping roof of a house. A longitudinal shock is bound to injure the pilot; if remembering that his wings will absorb a shock of extreme violence, he can avoid colliding with an obstacle nose on, he may then hope to escape severe injury. A simple example of this is the contrast between striking a tree nose on and allowing the nose of the fuselage to pass between two trees and so taking the whole shock on the wings.

There is a certain point after which it is impossible not to wreck the aeroplane; pilots so often lose their lives and those of their passengers in attempting the impossible by overstepping the margin of speed and control of the aeroplane

in the vain attempt to bring it down intact; in other words, once the pilot has decided that it is impossible to save the aeroplane, he must simply regard it as a shock absorber, and crash it, so far as possible, with the minimum risk to his crew.

PART IV.—EXPERIMENTS WITH MECHANICAL DEVICES TO ASSIST LANDING.

1. The "Palethorpe" Tail Skid.

People are apt to regard the present process of landing as a reasonably ordered sequence of events; I hope that to pilots of the future it will seem like a chapter of accidents. I have always felt that, so long as immunity from landing crashes is secured by a delicate mental organisation that may at any time break down, the aeroplane, as a commercial vehicle, will be open to criticism. Experiments have therefore been in progress for some time at the Royal Aircraft Establishment with a view to reducing the personal factor in landing. To assist the pilot in landing, Captain Palethorpe designed a special tail skid (see photograph). It took the form of a long skid attached in a similar way to the ordinary tail skid, and a dashpot was incorporated in its action. If the pilot glided down with a little engine so as to flatten the gliding angle, and partially flattened his aeroplane out prior to contact with the ground, the action of the long tail skid damped out the subsequent tendency to bounce. With this device Captain Palethorpe achieved some measure of success, and was able to make a remarkable demonstration of landing at night, with little or no ground illumination. His device was, however, rather a valuable aid to the pilot's judgment than a substitute for it.

2. The "Noakes" Ground Indicator.

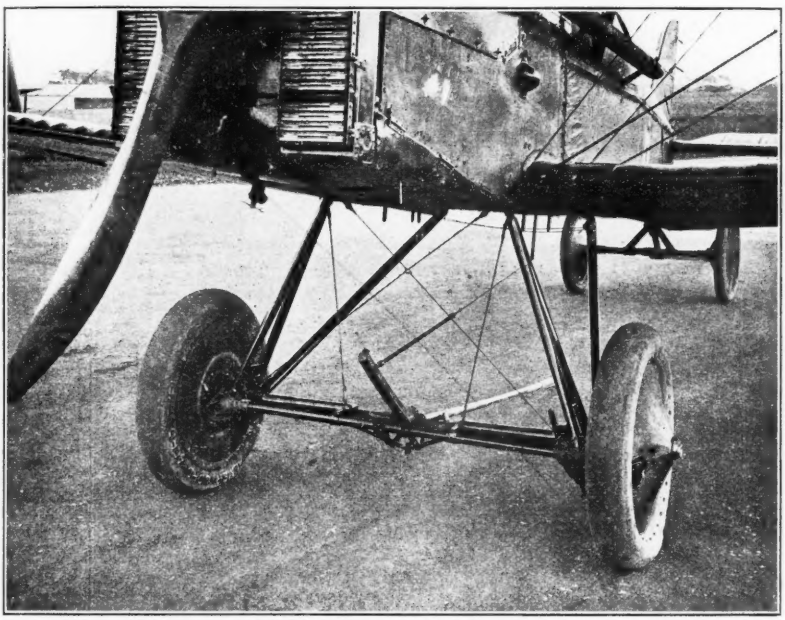
Flight Lieutenant Noakes, one of the most skilful exponents of manœuvre at low speeds, has subsequently carried out experiments with a device attached to the undercarriage of an S.E.5a (see photograph). It consists essentially of a long arm pivoted to a cross-member behind the wheel axle, and connected by elastic to the bottom of the control stick. This ground indicator is a device of a simple kind, and from its nature can only produce a simple movement. The elevator movements in landing are complex, but instead of trying to reproduce them, the device merely aims at substituting one or two simple operations for a complex effort of observation and judgment.

Extensive flying experiments have been carried out, and show the device to be a promising one. As the wheels of the aeroplane approach the ground the arm comes in contact with it, pulls back the control stick and flattens the aeroplane out. It has been found that landings can be made "hands off the control stick" if the pilot glides in with a little engine, and shuts it right off when the ground arm pulls back the control stick. Instead of curving up into the air again due to the stalling moment of the elevators, the aeroplane, because its engine is shut right off at the moment at which the elevators are automatically raised, sinks on to the ground in quite a good stalling attitude.

Now compare a landing with the indicator in action to an ordinary landing. In landing with the indicator, the pilot has certain definite operations to carry out, the performance of which is not based on an effort of rapid judgment. They are: the air-speed and engine revolutions at which to glide in, which are capable of being determined once and for all; and the moment at which to throttle right back, which is given to the pilot by the ground indicator when it pulls back the control stick. These are not obscure, but precise operations. Every landing without the indicator is a fresh problem, the successful solution of which is the result of long and habitual training.

Apart from the fact that the indicator is at a great disadvantage in a landing with engine stopped, efforts are being made to develop it further. Although

the pilot's instinctive elevator movements in landing are so complicated, it should not be impossible to study, analyse and reproduce them. For this purpose recording apparatus has been fitted to a Vickers Vimy in order that the elevator movements of landing may be investigated. A number of landings have already been made, records of which should form the basis for the contemplated development of the ground indicator. I am sanguine enough to hope that the pilot of a commercial aeroplane, provided that he has judged his entry into the aerodrome, and has set his aeroplane to glide at a steady speed, will be relieved of all further worry of landing. He will merely watch himself being landed.



The Noakes ground indicator.

3. The Future.

The development of a device such as the Noakes ground indicator opens up the larger problem of approaching and landing on an aerodrome safely in thick fog or darkness. Even a sure means of flattening the aeroplane out at the end of its glide would avail the pilot nothing were he not certain ultimately to arrive at the correct place on the aerodrome. To this place the pilot must somehow be conducted. It has now been proved that aeroplanes can be flown in continuous mist or cloud by the use of the turn indicator, cross level, air-speed and compass. It is probable that in the future commercial aircraft will fly above cloud and mist up to heights of at least 10,000ft. There are, however, very few days in which the clouds or mist are not in layers. If the mist is right down to the ground, there should be some convenient height at which an aeroplane could fly and be above it. On the other hand, there is frequently a clear space of 500ft. to 1,000ft. between thick layers of cloud and the ground.

It seems perfectly reasonable that an aeroplane flying at 8,000ft. could be brought to a position above the aerodrome and informed of the nature of the clouds by wireless; that by means of a series of captive balloons let up through

the mist the pilot could be given the exact location of the landing space, and enabled to estimate the gliding angle necessary to bring him to the required spot; finally, that the aeroplane could be flattened out at the end of its glide by a mechanical device. To make this sequence of operations not only possible, but safe, will need many experiments; but success would widen immeasurably the possibilities of civil aviation.

Could we visit an air port of the future on a day when it was enveloped in creeping mist, I do not think we should find it deserted. On one side aero-

The Palethorpe tail skid.

planes would glide in, looming up like shadows; on the other they would get off every few minutes, only to be blotted out in the mist. There would be no fuss; simply the impression of perfect organisation. I dare to conceive of an aerial liner, already a speck on the far horizon, overtaken by a swift aeroplane whose mission it will be to deliver a late mail. The mail carrier alights on it, after a short interval releases itself, and then comes flying home. A Sir Thomas Lipton of the future, having (against all regulations) alighted on and made fast to the upper deck of an aerial P. & O., may even invite himself to lunch with her captain; but that captain is still a very small boy.

THE DESIGN OF AEROPLANE CONTROL SURFACES, WITH SPECIAL REFERENCE TO BALANCING.

BY H. B. IRVING, B.SC.

In a recent article in " Engineering "* the writer has given an account of the principles which govern the design of aeroplane control surfaces, making special reference to wing ailerons. Included in the information presented were data on the properties of wing ailerons of the ordinary unbalanced form, but varying in span and chord length and fitted to wing tips of different plan forms. From these data several conclusions of practical importance were drawn, some of them finding general application in the design of control surfaces, and it may be useful to give a résumé of these before proceeding to deal with the balancing of control surfaces.

(1) All ailerons and elevators become relatively inefficient for movements above about 15° to 20° from the normal position, owing to a sudden reduction in the slope of the curve relating moment on machine with angle of aileron or elevator. For movements up to about 15° or 20° the moment is nearly proportional to the angle.

(2) Rolling moment or pitching moment per unit area of control surface decreases as the chord of the control surfaces increases. In the case of elevators on a tailplane of rectangular plan form, the actual pitching moment is nearly the same, for a given angular movement, for elevators of chords from 0.4 to 0.6 of the total tailplane chord.

(3) Hinge moment on unbalanced ailerons and elevators is roughly proportional to angular movement and to (area × chord) of aileron or elevator.

(4) Ailerons or elevators on a wing or tailplane having raked ends such that the leading edge is longer than the trailing edge are more " efficient " than those on a wing or tailplane having ends raked the reverse way. (Efficiency of control is defined as the ratio of the moment produced on the machine for a given movement of the control column to the effort required; comparison of efficiencies can only be made when the maximum control, that is to say, the maximum moment exerted on the machine, is the same in the different cases.)

(5) Maximum efficiency of control is obtained with ailerons or elevators of chord equal to about one quarter of the total chord of wing or tailplane. It may happen, however, that it is not possible to secure sufficient maximum control with elevators of these dimensions.

(6) The span of the aileron which gives maximum efficiency of control is about two-thirds of the semi-span of the aeroplane.

(7) The ailerons on the lower wing of a biplane are very slightly more efficient than the ailerons on the upper wing.

(8) Similar ailerons on both the upper and lower wings of a biplane are roughly twice as efficient as the same ailerons on the upper or lower wing only (the ailerons on one wing only being permitted roughly twice the range of movement of ailerons on both upper and lower wings, so that the maximum control is the same in the two cases).

(9) It is important that the gap at the hinge of a control surface should be kept as small as possible. In general, the effect of a gap at the hinge is to reduce

* October 8th, 15th, and 22nd, 1920.

the moment on the aeroplane which movement of the control surface produces, and, at the same time, to increase the hinge moment for small movements. The effect of a gap on the hinge moment is not nearly so marked as on the moment on the aeroplane, but the reduction of the latter may amount to as much as about 40 per cent. for a gap of half an inch on a total wing or tailplane chord of five feet.

By giving attention to the various points enumerated above, the designer may be able so to design the control surfaces of a fairly large machine that it is not unduly heavy on the controls, without resorting to the expedient of balancing, when otherwise balancing would be necessary. With increase in the size of the aeroplane, however, there comes a stage when even the most efficient unbalanced control surfaces become too heavy for the pilot's strength, and either balancing of the controls has to be adopted or control must be effected through some form of relay motor which performs the actual operation of moving the control surface. Various forms of relay control have been and are being tried, with promising results, but it is the opinion of the writer that, having regard to the relative simplicity and effectiveness of different methods of balancing the controls, and to the size of present day aeroplanes, a stage has not yet been reached at which it is profitable to employ relay control.

In the present paper it is proposed to discuss three methods of balancing, all of which have been adopted in varying measure in practice. These methods are:—

(*a*) The "horn" method;
(*b*) The method in which balance is obtained by hinging the control surface about an axis some distance behind the leading edge, hereafter termed the "backward hinge" method;
(*c*) The Avro patent method of balancing by means of a small plane placed above the (horizontal) control surface and forward of the hinge.

Before taking each of these methods in turn and discussing it, however, it will be as well to give some general consideration to the problem of balancing.

General considerations.

For geometrically similar aeroplanes at a given speed the force on the control column, or hinge moment required for a given movement of the controls, varies as the cube of the linear dimensions. Thus, for a machine which is, say, five times the size of a similar machine, the control surfaces must be balanced to such an extent that the hinge moment must be reduced to 1/125 of the unbalanced moment if the effort required for given settings of the control surfaces is to be the same in the two machines. This is, of course, an extreme statement of the case; for, generally speaking, the required proportion of control surface to total surface becomes less as the size of the machine increases. How much less it may become it would not appear to be possible to say definitely, in view of the absence at present of any specific information as to the requisite amount of controllability for aeroplanes of different types. Nevertheless, it is clearly seen that a very considerable reduction in hinge moment may require to be attained by "balancing" in a large machine, if the control is not to throw undue strain upon the pilot.

This being so, it becomes important to know how the amount of balance varies with the attitude of the aeroplane for any given system of balancing, in order to guard against the control members becoming overbalanced under certain conditions of flight and "taking charge" of the machine. Thus, consideration of the merits of different methods of balancing should include a study of the behaviour of the control surfaces at different angles of incidence and of yaw; and the effect on the balance of such manœuvres as a steeply banked turn, or a spin, should also be considered.

This paper will relate chiefly to the balancing of ailerons, and it should perhaps

first be explained exactly what is meant by the term "balanced" as applied in this connection. In the strictest sense, control surfaces may only be said to be balanced over a certain range of movement when the moment about the hinge of the control member is zero for all positions within the given range of movement. In the case of ailerons, however, which are always cross connected so that when they move downwards on one side of the machine there is a corresponding upward movement of those on the other side, the ailerons are balanced, *so far as the pilot is concerned,* when the algebraic difference of the hinge moments on the two sides is zero over a given range of movement of the ailerons. It will be "balancing" in this sense which is referred to in what follows.

The "horn" method of balancing.

By far the most common method of balancing ailerons is to have a "horn" or projection on the aileron beyond the wing tip and forward of the aileron hinge. It will be shown that there are several serious disadvantages attaching to this method, and that although it may be reasonably satisfactory for small aeroplanes, in which the degree of balance required is not great, the method is quite unsatisfactory, if not dangerous, when applied to the ailerons of a very large aeroplane, in which the object is to obtain a near approach to balance.

In the first place, it has been found that the degree of balance obtained with the "horn" method is very sensitive to slight changes in size and shape of the balancing "horn"; a very small addition to the "horn" may convert a practically unbalanced aileron to one which is very nearly balanced or even overbalanced. It would appear from this that when such variables as plan form and section of the "horn" and wing tip enter in, a designer is hardly in a position to design ailerons of this type to have any specified degree of balance, and the chances are that the ailerons as designed will actually be either overbalanced or very much underbalanced.

Another disadvantage attached to horn ailerons is the fact that they may give rise to tensions in the control wires which are large compared with the tensions which obtain when ordinary unbalanced ailerons are used. It has been found that with the latter the variation in hinge moment on an aileron with angle of incidence is not great, owing to the fact that the direction of flow near the aileron to a large extent follows the lines of the wing section regardless of the angle of incidence. With the projecting "horn" of an aileron, however, the case is different. The "horn" is not in the downwash of the wing, and as the angle of incidence of the wing increases so does the angle of incidence of the "horn," and at about the same rate, exerting an increasing moment in the opposite direction to that on the main portion of the aileron. This goes on until the "horn" reaches a critical angle, above which the force on the horn no longer increases, and the centre of pressure recedes towards the hinge, causing a very sudden reduction in magnitude of the balancing moment. The effect is illustrated by Fig. 1, which is taken from A.R.C.R. and M., No. 728,* and gives hinge moment on one aileron of the proportion shown, plotted against aileron angle. Each curve applies to a given angle of incidence of the wing, and it is seen that until the incidence of the aileron becomes large, the change of moment with aileron angle is comparatively small; that is to say, the ailerons are nearly balanced as far as the pilot is concerned. But at the same time the change of moment with wing incidence is seen to be great; it is roughly as great as the rate of change with aileron angle would be if the ailerons were ordinary unbalanced ailerons of the same span and chord. This means that there are large tensions in the control wires, even for the normal position of the ailerons, over a considerable range of angle of incidence; also it appears that the aileron is subjected to more

* "Investigation on Ailerons," Part IV. "The effect of yaw on the balance of ailerons of the 'Horn' type." By H. B. Irving and K. Batson.

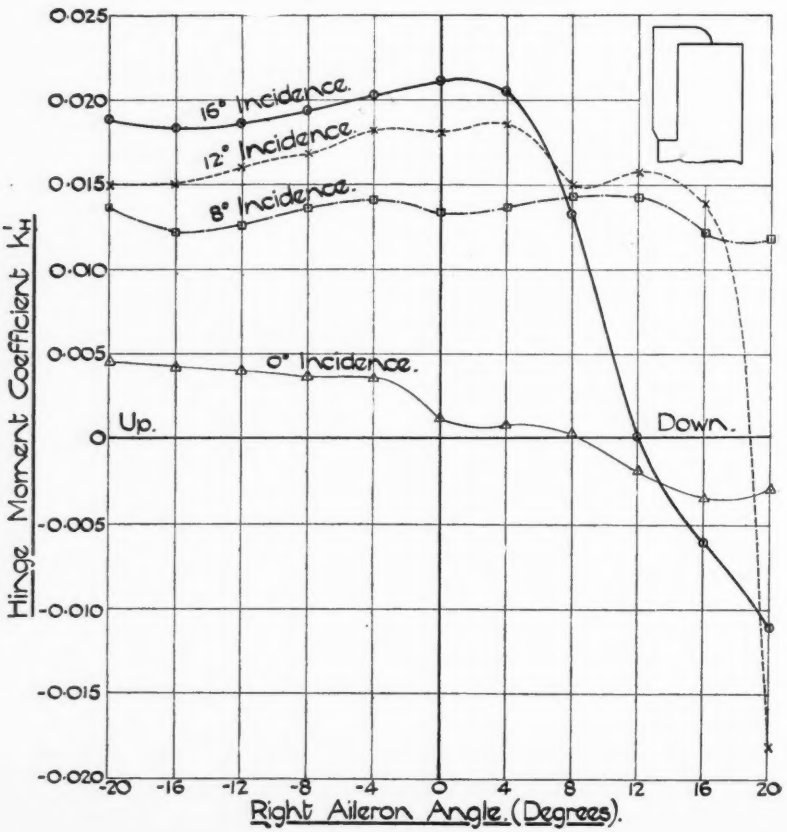
severe torsion than would be the case if it were unbalanced, and it is very difficult to make an aileron satisfactorily stiff against twisting action.

The actual balance of these ailerons, as felt by the pilot, is shown by Fig. 2, in which the algebraic difference of the moments on the ailerons on the two sides of the machines is plotted against aileron angle. It will be seen that until large angles of incidence and large aileron angles are reached there are no great changes in the balance; at angles of incidence of 12° and over, however, the range of aileron angle over which the ailerons are roughly balanced becomes smaller and smaller until at 16° incidence the ailerons are very stable over most of the range of movement.

Effect of yaw on " horn " ailerons.

As a result of flying experience with " horn " ailerons it was suspected by the R.A.E. that certain undesirable effects which had been observed were due to the effect of sideslip or yaw. Special experiments were accordingly made on the balanced ailerons of Fig. 1 with a view to investigating the effect of yaw on the balance of " horn " ailerons. The results of the experiments, which are given

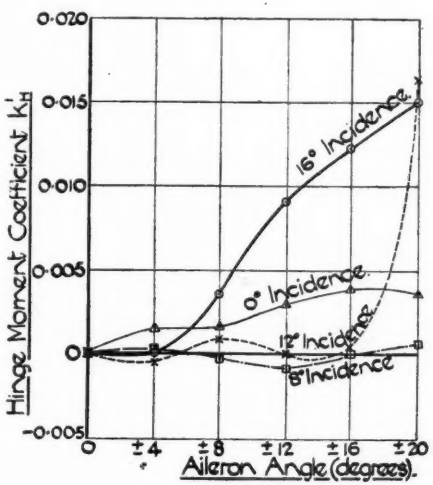
FIG. 1.



in A.R.C.R. and M., No. 728, showed that the effect of yaw was to make the ailerons overbalanced at certain attitudes over a varying range of movement of the ailerons; but whether or not yaw was the sole cause of the undesirable effects experienced in any operation involving turning could not be stated with certainty, because it was also found from the model experiments that there would be a tendency for the ailerons to take charge when turning in a small circle without sideslip, and a possibility of their taking charge when going into or during a spin.

It was found later that the above conclusions, based on model experiments, were borne out in a remarkable degree by previous observations made by Captain G. T. R. Hill during flying tests on an F.E.9 aeroplane with ailerons having a

FIG. 2.



large pointed horn. The results of these tests are given as an appendix to the report on the model experiments previously mentioned. It may be of interest to give in Captain Hill's own words a description of the behaviour of the control column of the F.E.9 aeroplane under various conditions of flight:—

"For ordinary straight flying and gentle turns the flaps are very good, though for stunting near the ground they are at present dangerous, even to an experienced pilot, as the amount of balance obtained seems to vary largely under different conditions.

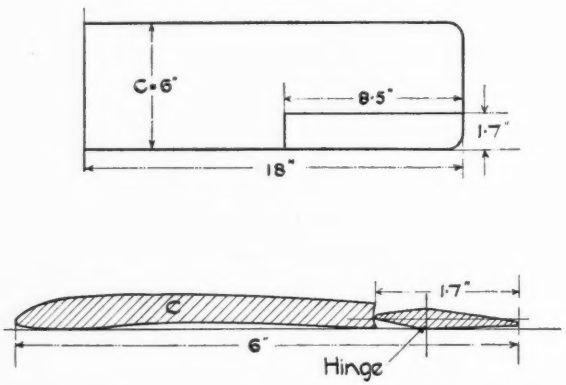
"If a steep turn to the left is started at 55 to 60 m.p.h. and 1,600 r.p.m., the speed cannot be kept below about 75 m.p.h. after a few seconds, and I was forced to push to the right with both hands and the rudder bar with my right foot with very nearly my whole strength in order to come off the turn. . . . Turning to the right the same feeling of the flaps taking charge is noticeable, though to a lesser degree.

"The aeroplane was slowly stalled and spun to the right and the stick was held comparatively loosely; it was steadied rather than held, and lateral movement was free to take place if large force was applied to the stick by means of the ailerons. Just at, or about, the moment of stalling, as right rudder was being applied, and the stick was being quickly eased back and to the left, it suddenly flicked right over to the right, the aeroplane put its nose down and commenced to spin, and the stick immediately became quite

loose again and came over to the left, this being the position for spinning. The pilot has to resist an impulsive force of considerable magnitude to hold the stick across to the left while starting a spin to the right.

"When flying about level, hands off the stick, well throttled down at under 50 m.p.h., the aeroplane was trimmed gradually slower by means of the trimming wheel. As the speed approached within 2 or 3 m.p.h. of stalling speed, which is about 42 m.p.h., one wing, usually the port wing, would commence to drop slowly; the stick would then commence to move across to the left, thus giving more left bank and tending to exaggerate the amount the wing was dropping. The stick was quite heavy to pull to the right, instead of feeling very loose and sloppy like unbalanced ailerons feel when nearly stalling."

FIG. 3.



The general conclusion reached regarding horn ailerons is, then, that although they may be reasonably satisfactory for small aeroplanes, in which the degree of balance required is not great, and in which the moment is easily controlled even if the ailerons do become overbalanced under certain conditions, they cannot be regarded as at all suitable for large machines; in fact, they may even be dangerous if too near an approach to balance is made.

The "backward hinge" method of balancing ailerons.

In a recent research on the balancing of ailerons,* made at the National Physical Laboratory, experiments were made on a type of aileron which, it was thought probable, would not suffer from the drawbacks of the horn type and which, moreover, had been tried in practice by the Handley Page Company on their largest aeroplane and found to be satisfactory. In this type the aileron is balanced by placing the hinge back some distance from the leading edge of the aileron, the portion of the aileron behind the hinge conforming to the wing section, while the portion in front is shaped so as not to protrude, or to protrude only very little, outside the wing section when the aileron is moved up or down, as illustrated in Fig. 3. Possible variations of the method are illustrated in Figs. 4a, b and c. Fig. 4a shows the type of aileron adopted by the Germans in one of their Albatross fighting machines; Fig. 4b the type adopted in the Flugzeubau Friedrichshafen Bomber. In both these types the portion of the aileron forward of the hinge is

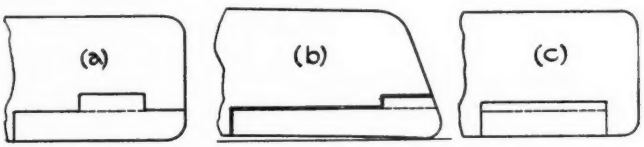
* R. & M., 651. "Investigation on Ailerons," Part III. "The balancing of Ailerons," by Irving & Ower.

not shaped so as to lie inside the profile of the wing section but conforms to it, so that movement of the aileron causes the portion forward of the hinge to project above or below the wing. The variation illustrated by Fig. 4c has not yet, so far as is known, been adopted in practice for balanced ailerons, but it is adopted in the " Panther " ship aeroplane for unbalanced ailerons. All the experiments were made on a 6in. × 36in. unstaggered biplane with " square " shaped wing tips, measurements being made of hinge moment and rolling moment. They were designed to give information on the following points:—

(1) Effect of variation of position of hinge.
(2) Effect of variation of angle of incidence of wings.
(3) Effect of yaw.
(4) Difference in balance of upper and lower ailerons.
(5) Effect of gap between nose of aileron and wing.
(6) Effect of ailerons, when in normal position, on the lift and drag of the wings.

For a full account of the experiments reference should be made to the report mentioned. The main results and conclusions are given, however, in what follows.

FIG. 4.



Variation of position of aileron hinge.

The first set of experiments was made on a series of ailerons having the hinge placed at various distances from the leading edge. For each position of the hinge the portion of the ailerons forward of the hinge was shaped so that when the ailerons were set at an angle of 15° up or down the lower or upper surfaces of the forward part of the ailerons were then flush with the wing surface.

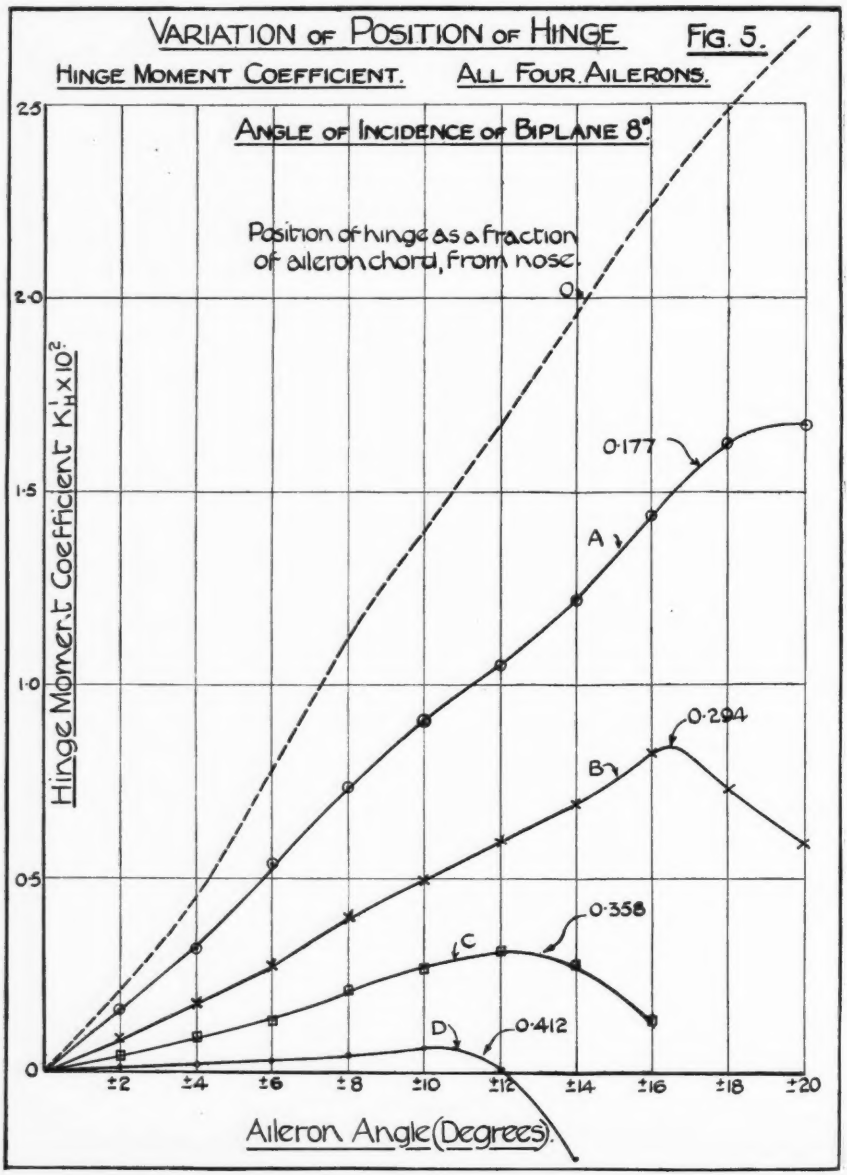
The resultant hinge moment on all four ailerons is plotted against aileron angle in Fig. 5 for the different positions of hinge. A curve obtained from estimation of the hinge moment for ordinary unbalanced ailerons is also plotted on this figure in order that the degree of balance which is obtained in the various cases may readily be judged. When the hinge is one quarter of the aileron chord from the nose the hinge moment is halved. Cross-plotting from these curves and slight extrapolation shows that when the hinge is at 0.425 of the aileron chord from the nose the ailerons become practically completely balanced up to an angle of about ± 10°, above which angle they become overbalanced. Ailerons of this type which are required to be very nearly balanced should therefore have a range of movement not greater than ± 10°.

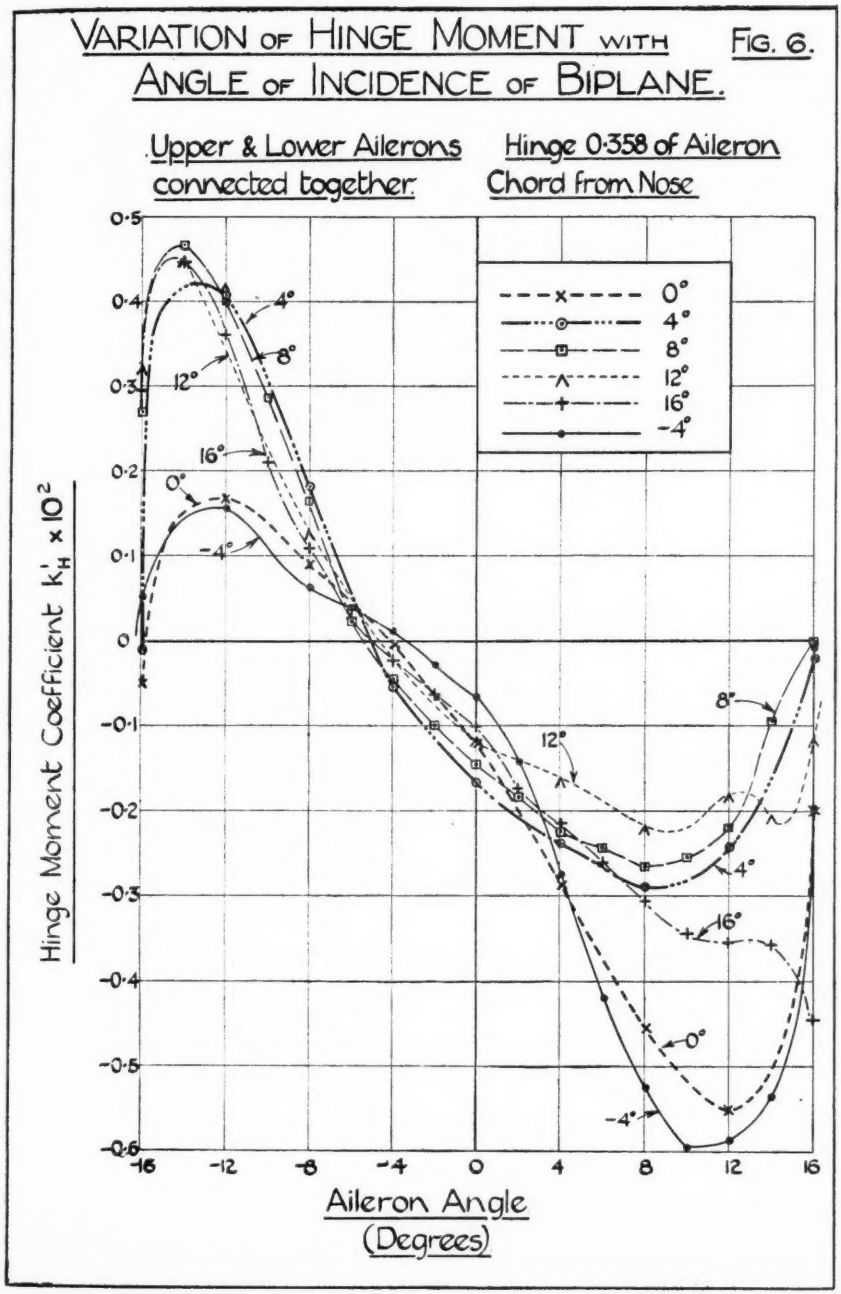
As regards rolling moment little need be said. Curves of rolling moment against aileron angle are practically straight lines over the working range of angle and there is a progressive decrease in the value of the rolling moment as the hinge is moved aft; the rolling moment due to the completely balanced ailerons is about 75 per cent. of the rolling moment due to the unbalanced ailerons of the same size.

Variation of balance with angle of incidence of biplane.

The ailerons chosen for the tests on the effect of variation of angle of

incidence were those with the hinge at 0.358 of the aileron chord. In fact, in all the experiments subsequently described the hinge was in this position. Tests were made at angles of incidence —4°, 0°, 4°, 8°, 12° and 16° on upper and lower ailerons connected together. Hinge moment for the two ailerons on one side of the biplane is plotted against aileron angle in Fig. 6 and for all four ailerons in Fig. 7 for the various angles of incidence.

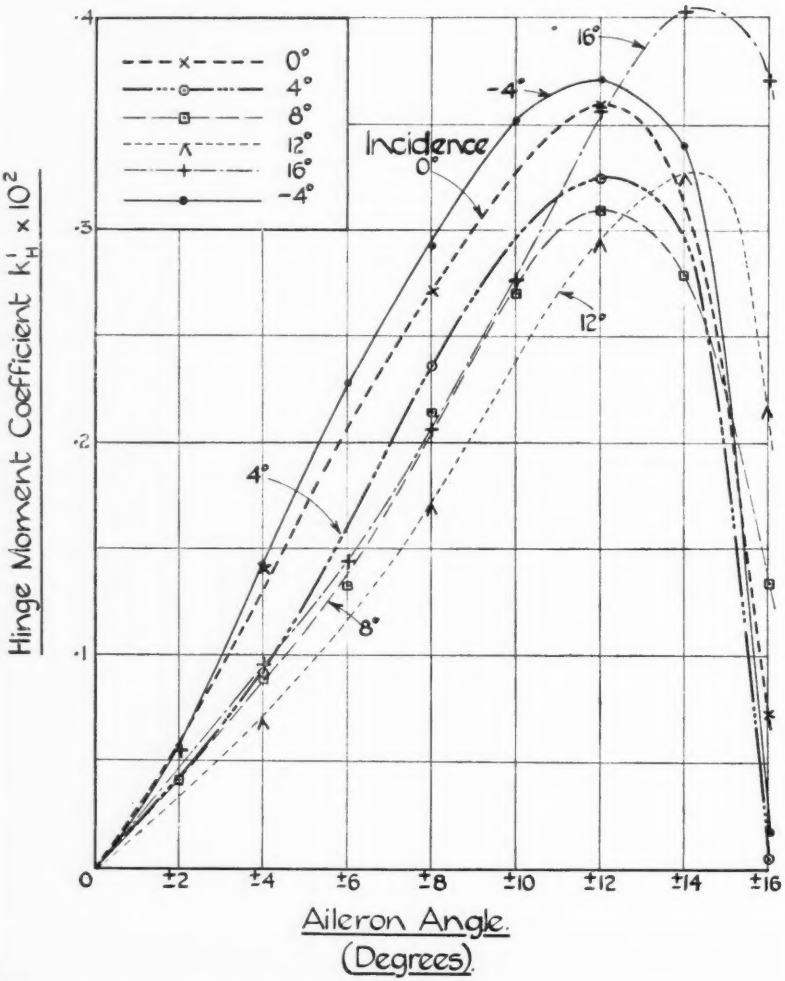



VARIATION OF HINGE MOMENT WITH ANGLE OF INCIDENCE OF BIPLANE.
FIG. 6.
Upper & Lower Ailerons connected together.
Hinge 0·358 of Aileron Chord from Nose
0°
4°
8°
12°
16°
-4°
Hinge Moment Coefficient $K'_H \times 10^2$
Aileron Angle (Degrees)
0·5
0·4
0·3
0·2
0·1
0
-0·1
-0·2
-0·3
-0·4
-0·5
-0·6
-16
-12
-8
-4
0
4
8
12
16

VARIATION OF HINGE MOMENT WITH ANGLE OF INCIDENCE OF BIPLANE. FIG. 7.

All Four Ailerons.

Hinge at 0·358 of aileron chord from nose.



It will be seen from Fig. 6 that the variation in hinge moment with angle of incidence, for either upward or downward movement of the ailerons, is quite considerable. For about 12° upward movement the hinge moment at angles of incidence 4°, 8° and 12° is roughly double the hinge moment at — 4° and 0° incidence; while for downward movement the reverse is true. Even so, the absolute variation of hinge moment with angle of incidence at a given setting of the aileron is quite small compared with the variation found in the case of ailerons of the " horn " type.

When the ailerons are cross connected the reverse effects of incidence, for upward and downward movements, to some extent cut out and the variation in resultant hinge moment becomes comparatively small as shown by Fig. 7. The curves of this figure show that from — 4° to + 12° incidence there is a continuous decrease in the hinge moment, but the curve for 16° lies very near the curve for 8° incidence, except at the larger aileron angles, where it rises considerably above the 8° curve. Both the curves at 12° and 16° incidence reach their maxima at an angle of about 14°, whereas the other curves reach theirs at about 12° aileron angle.

At 10° aileron angle the variation in coefficient of hinge moment per unit area, k'_H, is from 0.0035 for — 4° incidence to 0.0024 for + 12° incidence, a difference of 0.0011. It would appear probable that the absolute amount of variation in k'_H would not be much less for ailerons more nearly balanced than the ones under consideration. That is to say, the minimum value of k'_H at top speed of an aeroplane must probably be of the order of 0.0010 for ailerons at ± 10°, if the ailerons are not to become overbalanced at the speed corresponding to about 12° incidence; or, comparing this value with the corresponding value for unbalanced ailerons (Fig. 5), the maximum reduction of hinge moment feasible with this type of balanced aileron is about one-fourteenth.

Some idea as to what this means quantitatively may be given by a numerical example. Taking a large biplane with a wing chord of 15ft. and ailerons similar to those at present under consideration, fitted on both upper and lower wings, the hinge moment (corresponding to $k'_H = 0.0010$) required to move the ailerons through ± 10° comes out at about 280lbs.-ft. at a forward speed of 100 miles per hour. In a machine of this size the above figure might correspond to a force on the control column of about 28lbs. to be applied by the pilot, representing the minimum if the ailerons are not to become overbalanced at some speed below 100 miles per hour. It would appear then that with this type of aileron, hinge moment can be reduced to a magnitude which is within the pilot's strength even in the case of very large aeroplanes. Further, it should be noted that if there is any tendency towards overbalance it would occur at the larger angles of incidence and the lower speeds, when there would not be so great a danger of the ailerons taking charge.

The variation of rolling moment with angle of incidence is of a similar nature to that found for unbalanced ailerons. (See article in " Engineering," loc. cit.)

Balance of upper and lower ailerons separately.

Tests made to determine if there were any difference in the balance of upper and lower ailerons showed that the lower ailerons were very slightly more nearly balanced than the upper ones, the difference in hinge moment coefficients amounting to about 0.0005 at ± 10° aileron angle.

Variation of balance with angle of yaw of biplane.

The general conclusion drawn from tests made with the biplane yawed ± 20° was to the effect that, with the type of aileron under consideration, yaw has comparatively little effect either on hinge moment or rolling moment. Any effect

experienced was a reduction in both cases, but its magnitude was, in general, less than the variation of moment with angle of incidence.

Effect on balance of gap between nose of aileron and wing.

Attention has already been drawn to the fact that, in the case of unbalanced ailerons, even a small gap between aileron and wing considerably affected both rolling and hinge moments, particularly the former. Accordingly, as hinge moment is the quantity which is of primary importance in balancing, and as the effect of gap on rolling moment will almost certainly be of the same order of magnitude for balanced as for unbalanced ailerons, experiments on the effect of gap were made on hinge moment only; but further experiments, to be described later, were made on the effect of gap on lift and drag of an aerofoil, fitted with a continuous flap along the whole span, similar to the ailerons on the biplane.

In the case of unbalanced ailerons, the effect of gap at the hinge was to increase the slope of the curve of hinge moment against aileron angle, an effect which might have been predicted from the results of measurements of pressure distribution. Similarly, observation and deduction are in agreement as to the effect of gap on ailerons which are balanced, or nearly so, by the method under consideration; but in this case the effect is the reverse; gap makes ailerons which are nearly balanced still more nearly balanced. And the effect is, of course, relatively much bigger for balanced than unbalanced ailerons, as is illustrated by Fig. 8, which shows that a gap of 0.045 inches in a 6-inch chord almost halves the hinge moment.

In all the experiments hitherto described on balanced ailerons of the type now being considered, the rear edge of the wing was made with a radius appropriate to the position of the hinge of the aileron. It would be more convenient in practice to make this edge flat, in which case a gap, increasing in size as the aileron moved up or down, would be formed. The effect of such a gap could be estimated from previous results, but it was decided to make direct tests of the effect. The results showed the effect on hinge moment to be quite small (see Fig. 8) while on rolling moment there is a reduction which does not amount to more than about 13 per cent.

Effect of shaping the aileron nose and of gap on lift and drag.

In the first place it was desired to know what alteration in wing performance would follow as a result of shaping the ailerons, in the manner previously described, so that their portions forward of the hinge did not project above or below the wing when the ailerons were moved up or down. In the second place it was desired to know the effect of gap on lift and drag.

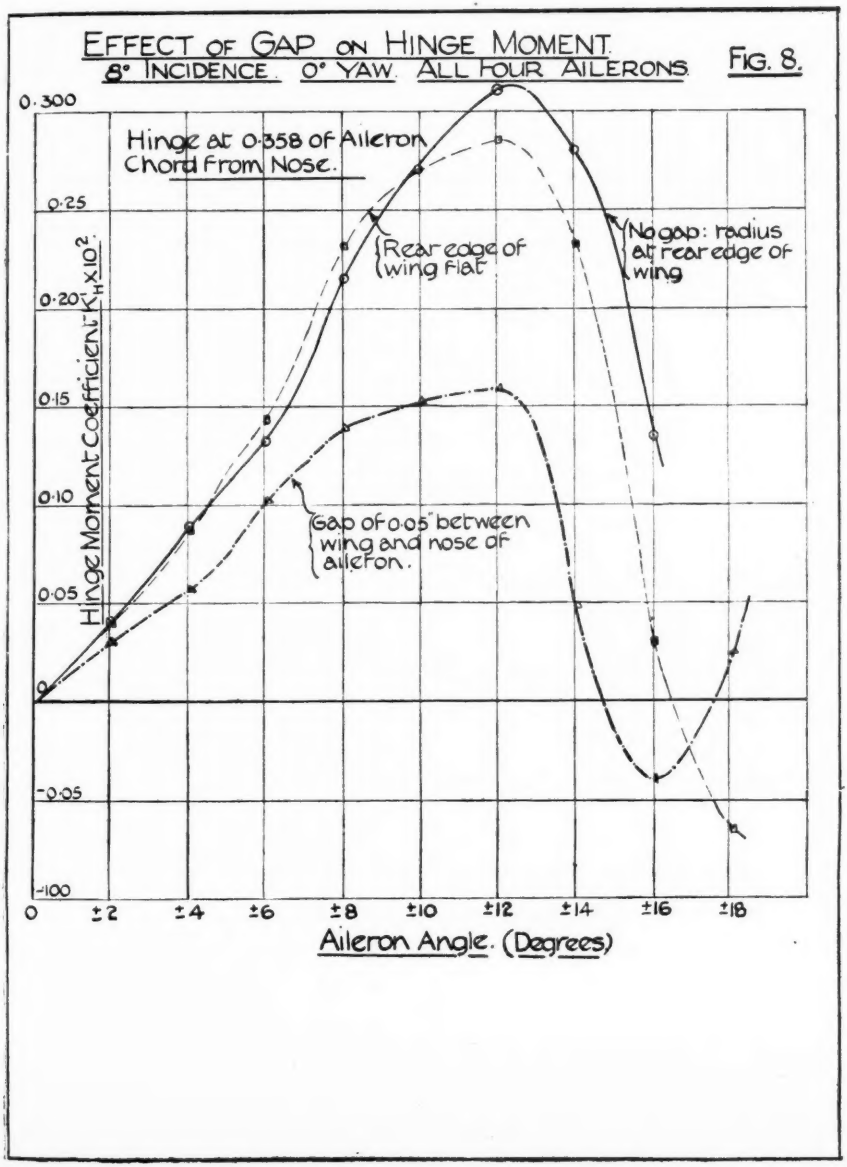
Both these effects were studied on an aerofoil of 6in. chord fitted with a continuous flap along the whole span, whose section was the same as that of the ailerons on which the majority of the tests were made. Lift and drag were measured in the wind tunnel in the usual manner with the flap in its normal position in the three cases:—

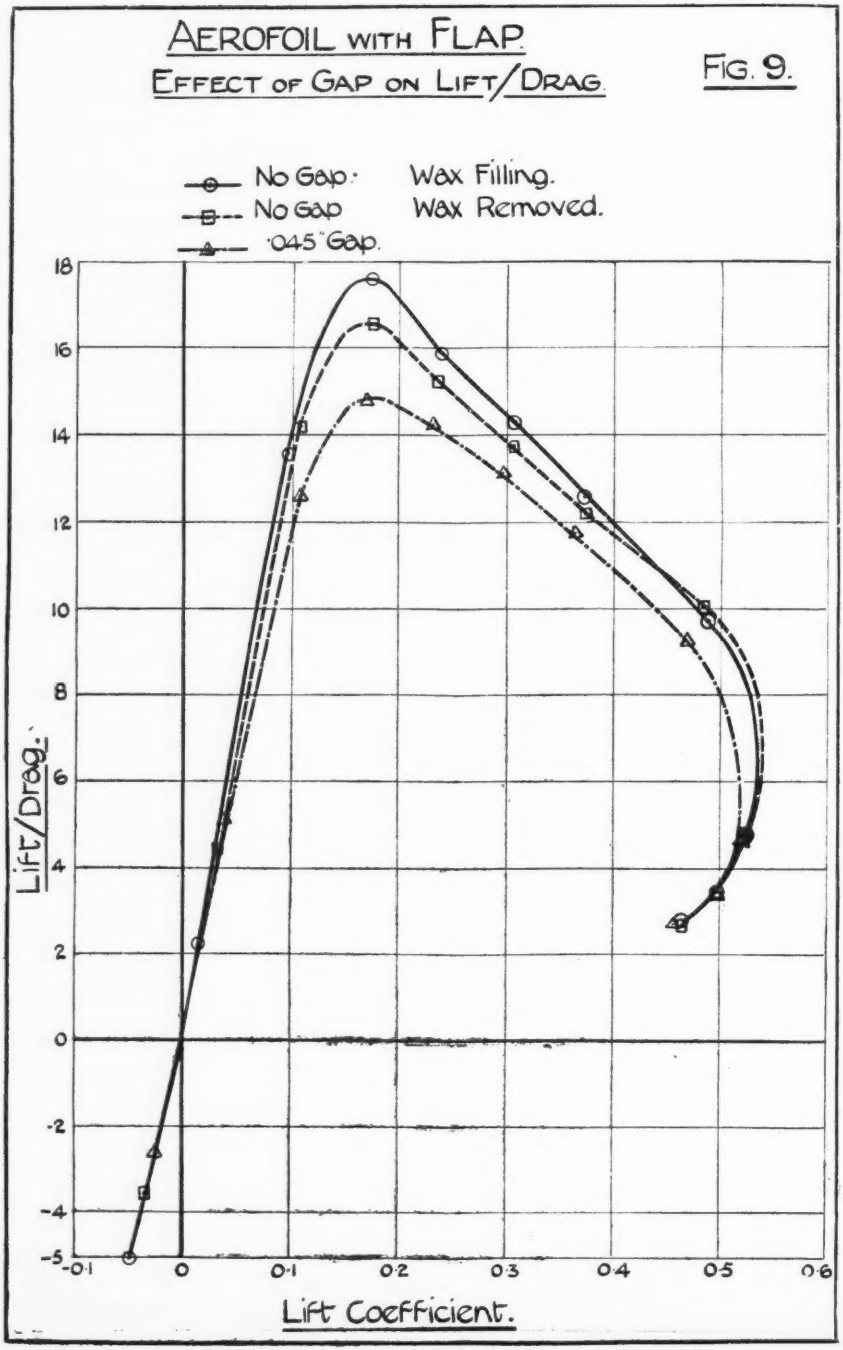
(*a*) Aerofoil made up to full section (R.A.F. 15 nearly) by means of wax filling.
(*b*) Wax removed.
(*c*) Flap adjusted to leave a gap of 0.045in. between flap and wing.

The results show that in both cases (*b*) and (*c*) lift is reduced while the drag is increased, both decrease and increase being considerably more in case (*c*) than in case (*b*); but in neither case is lift affected greatly. As for drag, the shaping of the ailerons increases minimum drag by about 3 per cent. and the gap increases it by a further 9 per cent. The combined effect on lift and drag is shown by

Fig. 9, from which it is seen that the maximum lift/drag ratios in the three cases (*a*), (*b*) and (*c*) are 17.6, 16.5 and 14.9 respectively.

It would appear that the reduction in efficiency of the wings due to shaping of the ailerons is not a serious matter, especially when it is remembered that the ailerons do not, in general, extend along the whole span of the wings.




AEROFOIL WITH FLAP.
EFFECT OF GAP ON LIFT/DRAG.
FIG. 9.
No Gap. Wax Filling.
No Gap Wax Removed.
·045" Gap.
Lift/Drag.
18
16
14
12
10
8
6
4
2
0
-2
-4
-5
-0·1
0
0·1
0·2
0·3
0·4
0·5
0·6
Lift Coefficient.

The reduction in wing efficiency due to gap, however, it would be well worth while either to eliminate or to reduce to a negligible amount by making the gap as small as practicable. It may be mentioned that the size of gap tested in these experiments corresponds to a gap which is slightly smaller than the actual gap measured on one of the Handley Page V. 1,500 machines, where it was as much as 1.2 inches. Such a gap as this would reduce the top speed by about a mile an hour and add a sum of the order of one hundred pounds to the running costs over the life of a machine.

Ailerons of full wing section, unshaped at the nose.

Before discontinuing experiments on the particular type of aileron under consideration, it was thought that it would be of interest to examine the behaviour of ailerons in which the full wing section was continued right to the nose of the aileron and to test if the position of the hinge for balance were greatly different from that in the case of ailerons with shaped nose.

The results were rather remarkable. Keeping the hinge in the same position as before, the ailerons, instead of being not quite balanced, were now decidedly overbalanced for angles up to about $\pm$ 8°, where a very rapid change in the value and sign of the hinge moment took place, and the ailerons became more stable than ailerons with shaped nose. Accompanying the change in hinge moment there was also a rapid change in rolling moment. The slope of the rolling moment curve up to about $\pm$ 8° aileron angle was slightly greater than the slope for the ailerons with shaped nose. There was then a sharp fall in the rolling moment till it reached a value not much greater than half its value at 8° after which it changed only very slowly with aileron angle.

In view of the erratic behaviour of these ailerons, they hardly appeared to be suitable for adoption in practice, and no further experiments on them were made.

General conclusions.

The main conclusion to be drawn from the results of the experiments on ailerons balanced by the method described seems to be that this method should meet satisfactorily the requirements of the present day. If, however, there is in the future a still further large increase in size of aeroplane the method might fail; because in a very large machine the variation with attitude of the amount of balance of the ailerons might assume proportions so great—relative to the strength of the pilot—as to convert the ailerons of the machine from being easily controllable at one attitude to being either overbalanced or too heavy on the control at another attitude.

Ailerons balanced by the Avro patent method.

It is only comparatively recently that experiments have been made on a further method of balancing ailerons, namely, that patented by Messrs. A. V. Roe and Co., Ltd.; here again the method has been tried in practice and is stated to have been proved satisfactory. Balance is obtained by mounting a small balancing plane above the aileron, forward of the hinge, as shown by Fig. 10, which is reproduced from a photograph of the Avro "Manchester" aeroplane kindly supplied by Messrs. A. V. Roe.

The experiments were made on the same model biplane as was used for the experiments on the "backward hinge" ailerons, and with ailerons of the same size. A drawing of the wing with aileron and balancing plane used in the experiments is given in Fig. 11.* Only the upper aileron had a balancing plane attached,

* Taken from A.R.C. Report. R. & M. 696. "The balancing of Ailerons by the Avro Patent Method." By H. B. Irving and A. S. Batson.

as in the "Manchester"; the area of this plane is 14.6 per cent. of the area of two ailerons and nearly 2 per cent. of the semi-wing area. Measurements of hinge moment and rolling moment were made on upper and lower ailerons connected together, both with and without the balancing plane and its supporting arms in position, and at 0°, 8° and 16° angles of incidence.

Hinge moment per unit aileron area for upper and lower ailerons on one side is plotted for both cases in Fig. 12, the area taken in each case being the same, namely, the area of two ailerons without balancing plane, so that the curves give a comparison of the actual hinge moments in the two cases. From the positions where the curves of this figure cross each other it may be seen that for all three angles of incidence the moment due to the balancing plane is zero when the ailerons are about 8° up. As the balancing plane is set at an angle of + 7° with the wing chord, it would appear probable that the chord of the balancing plane should be set about parallel with the wing chord, if minimum drag of balancing plane and wing are to occur at the same wing incidence.

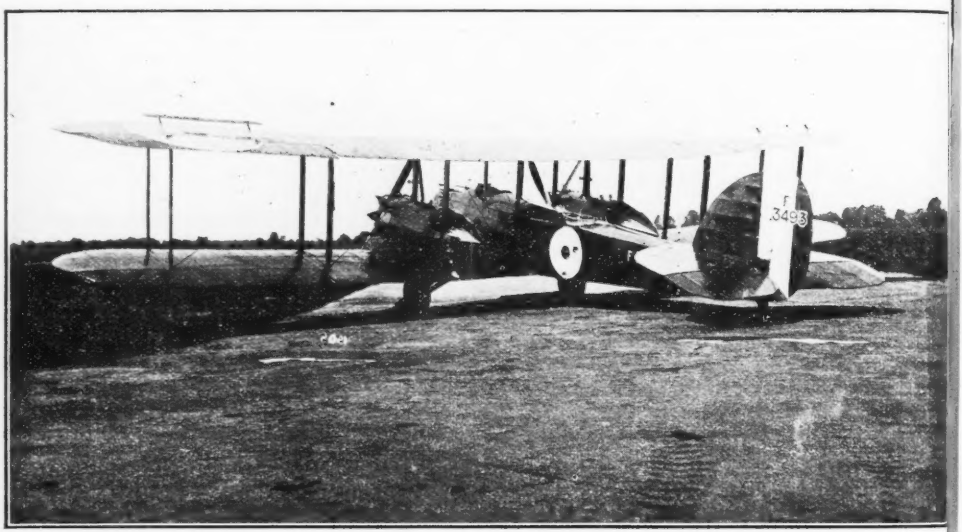


FIG. 10.—*Avro "Manchester" with small balancing plane.*

Hinge moment per unit aileron area is plotted for all four ailerons of the biplane in Fig. 13, which shows at once the reduction in moment due to the balancing plane. Expressed as a percentage, the reduction is greater for small than for large aileron movements; at ± 8° aileron angles the moment is reduced to about 65 per cent. while at ± 16° aileron angles it is reduced to about 75 per cent.

The curves of Fig. 13 also indicate that the degree of balance decreases as the stalling angle is approached, but not by so great an amount as to be important when the accompanying reduction in speed of flight is considered.

Assuming that a similar balancing plane fitted to the lower aileron would behave in the same manner as the balancing plane on the upper aileron, the addition of such a plane would make the ailerons balance to an extent about as great as designer would care to go. This degree of balance would be secured at a cost of about 5 per cent. increase in total wing drag, as against about 1½ per cent. by the "backward hinge" method of balancing.

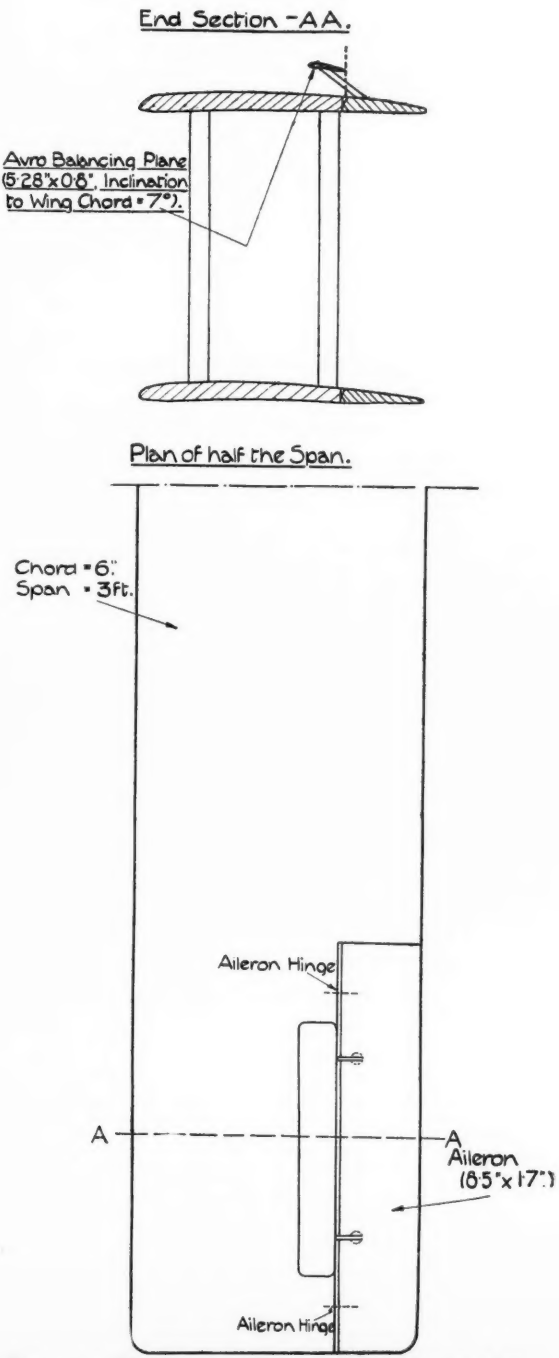


FIG. 11.—*Diagram of aileron with balancing plane.*

Balancing of rudders and elevators.

So far as the writer is aware, no systematic series of experiments have been made on the balancing of rudders and elevators. This would appear to indicate that the balancing of these control members is either not such a difficult problem or not so urgent as the balancing of ailerons.

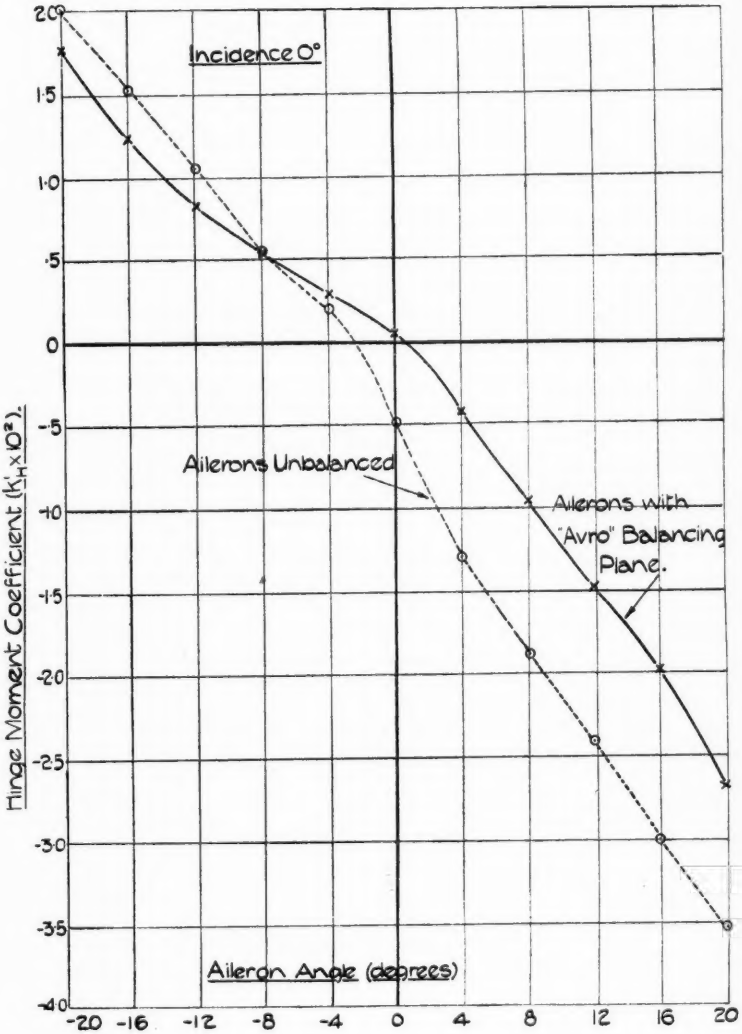
As regards the relative needs for balancing the different controls as the size of the aeroplane increases, it is thought that the ailerons come first, followed by the rudder and the elevators.

Balancing of the rudder does not appear to present any very great difficulties. The " horn " method in this case does not suffer from the serious disadvantages which are met with in applying it to ailerons; but if it is desired to make a near approach to balance, this can hardly be done without experiments on the particular design in question. Further, the position of the balancing portion relative to the slipstream of the airscrews has to be carefully considered, since it is possible that if the balancing portion is in a region of higher velocity than the other portions the effect of the slipstream may be to make the rudder overbalanced.

It is not clear that in the case of rudders there is any special need for methods of balancing alternative to the horn method. Should it be proved, however, that there is a need, it is quite possible that either the " backward hinge " or the Avro method could be successfully applied. The angular movement of rudders is usually considerably greater than that of ailerons; also the chord of a rudder is usually much larger compared with the thickness than is the chord of an aileron compared with its thickness. So that, if the hinge is placed backward some distance, only a small angular movement is required to bring the leading edge of the rudder outside the fin, making a gap and causing discontinuity in hinge moment with possible overbalance. But fins and rudders could be made thicker and of greater height so that the rudder would have a greater aspect ratio and could move through a large angular range without projecting beyond the fin.

With regard to the balancing of elevators, similar disadvantages apply in some instances to the horn method as apply in the case of ailerons. It has been seen that whilst it was possible so to balance an aileron that there was little or no change of moment on it with angular movement relative to wing, it was not possible by the horn method to avoid a large moment on the aileron as the angle of incidence altered. This did not affect the pilot, however, by reason of the cross-connection of the ailerons, but it would be of great importance in the balancing of elevators. The effect of the slipstream on the balance has also generally to be considered, as with balanced rudders.

As regards alternative methods to the horn method of balancing elevators, similar remarks apply to elevators as have been applied to rudders.


Incidence 0°
Ailerons Unbalanced
Ailerons with "Avro" Balancing Plane.
Hinge Moment Coefficient ($K'_H \times 10^2$).
Aileron Angle (degrees)
2·0
1·5
1·0
·5
0
-·5
-1·0
-1·5
-2·0
-2·5
-3·0
-3·5
-4·0
-20
-16
-12
-8
-4
0
4
8
12
16
20

Hinge Moment for Two Ailerons.

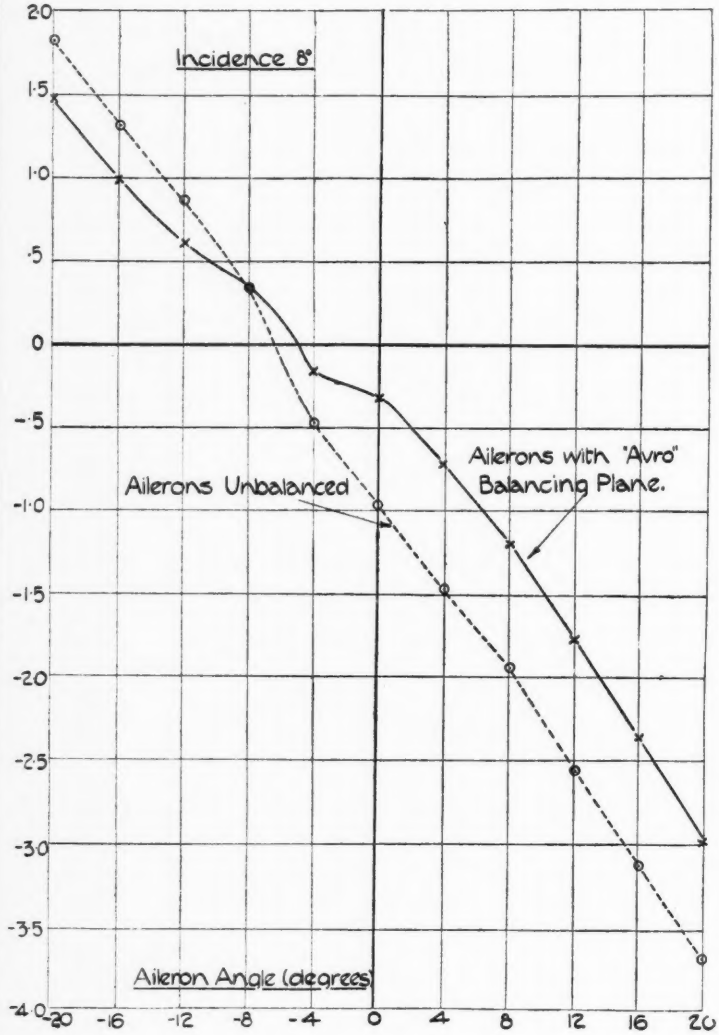


Fig 12.

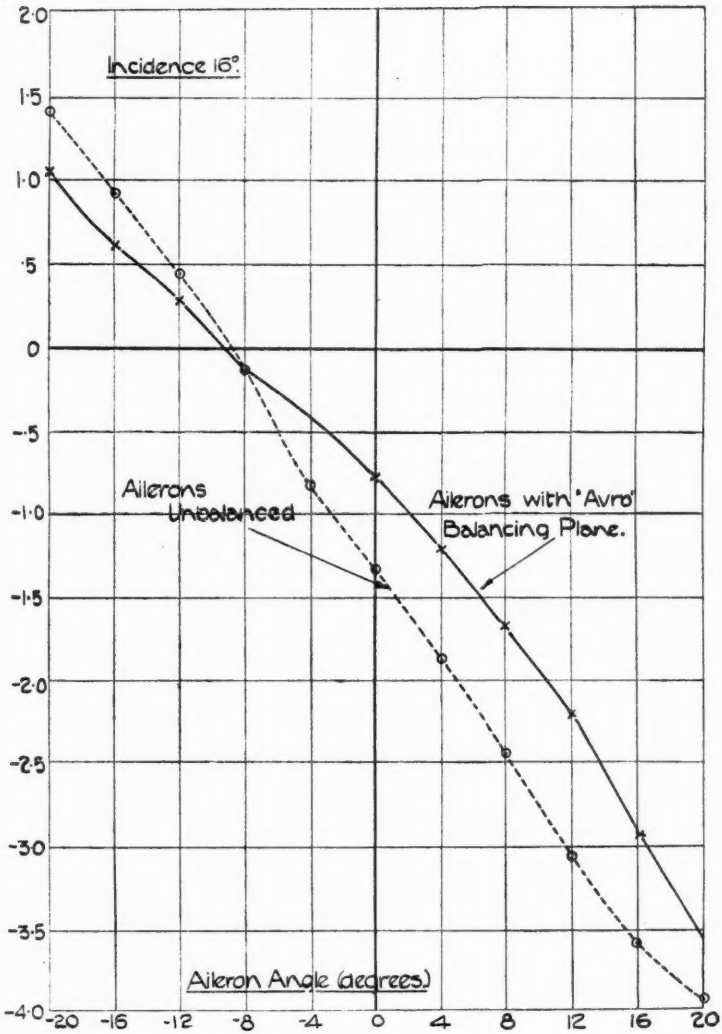
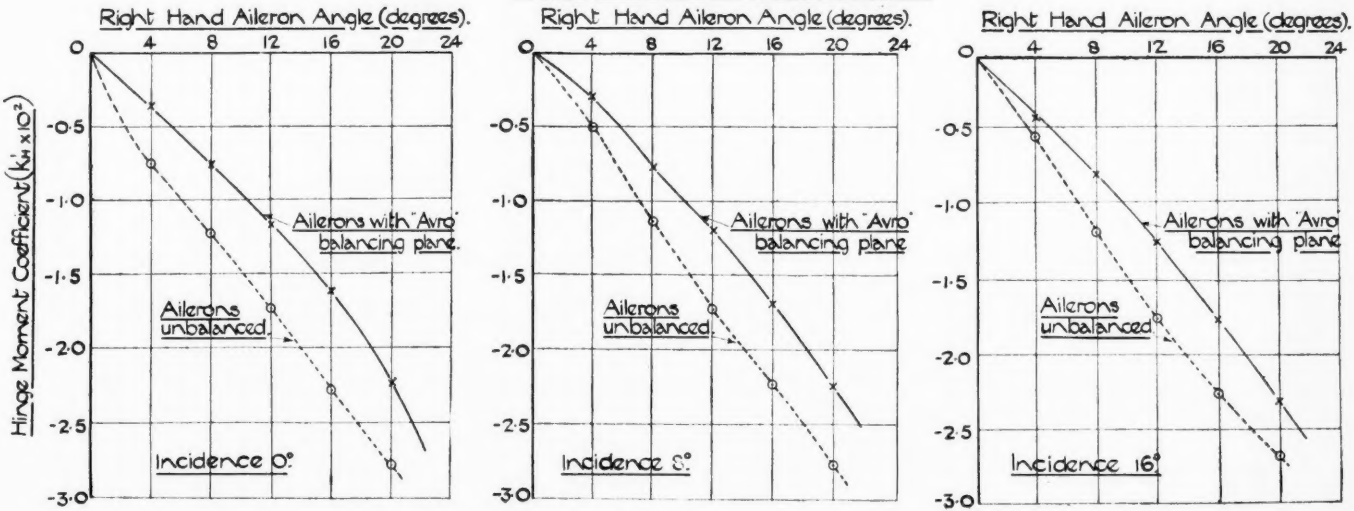

Incidence 16°.
2·0
1·5
1·0
·5
0
-·5
-1·0
-1·5
-2·0
-2·5
-3·0
-3·5
-4·0
Ailerons Unbalanced
Ailerons with 'Avro' Balancing Plane.
Aileron Angle (degrees.)
-20
-16
-12
-8
-4
0
4
8
12
16
20

Fig. 13.

Hinge Moment for all four Ailerons.



STAGGERED SPAR SECTIONS.

BY H. P. HUDSON, M.A., SC.D., A.F.R.AË.S.

It has been suggested that strut fittings could be made neater, on a staggered aeroplane, if the spar web were given the same stagger. Then the principal axes of the section are not in the direction of either the loading or the supports. The result may be an increase of both bending and shear stress; not more than it is possible to provide for, but involving an increase of weight likely to be more than the gain in the fitting.

I.—BENDING.

The usual expression $\pm My/I$, for the stress at any point of a bent beam, assumes that the bending is about a principal axis of the section. If the loading is oblique, and M_y, I_z are the bending moment and moment of inertia about the first principal axis OZ, and M_z, I_y about OY, then the stress at a point of the section whose co-ordinates are y, z, is

$$M_y y/I_z + M_z z/I_y.$$

For a rectangular section, the worst stress is the sum of the worst stresses due to the two principal components separately, but for a section with rounded corners the worst stress occurs at the point of the section farthest from the neutral axis, which is at an angle

$$\tan^{-1}(M_z/I_y)/(M_y I_z) \text{ to } OZ,$$

and does not coincide with the axis of the resultant couple at

$$\tan^{-1}(M_z/M_y) \text{ to } OY.$$

If the spar section is unsymmetrical it may be more convenient to use axes which are not principal axes of the section. The expression for the stress is

$$\{ M_y (yI_y - zP) + M_z (zI_z - yP) \} /(I_y I_z - P^2),$$

where P is the product of inertia $\int yz dA$, which vanishes only for the principal axes.

But besides this, we may also have altered values of the component couples M_y, M_z. Consider an aeroplane spar of staggered section under vertical loading W. This causes deflection which is not in a vertical plane, but has a horizontal component, for which the intermediate drag struts, if any, are points of support, and which also produces loads in the ribs and a horizontal loading on the rear spar, which in its turn produces oblique deflection of the rear spar. If both spars carry loads in both directions, these all affect the component moments and deflections of either spar.

Let W_F, W_R, w_F, w_R be the lift and drag loads per unit lengths on the front and rear spars. Since there is an unknown transference of drag through the ribs, we do not know w_F and w_R, but only their sum w; but the horizontal deflections of the two spars are assumed the same at all points.

We must resolve in the principal planes in order to use the differential equations of bending in their simplest form

$$EI\, d^2y/dx^2 = M;$$

but in the vertical and horizontal planes in order to use the statical equations of moment in their simplest form

$$M = M_A - R_A x + \tfrac{1}{2} W x^2,$$

in terms of the fixing moment and shear at the nearest support A; since the intermediate drag strut is a point of complete support against the horizontal deflection, but only of partial support in a principal plane.

Combining the equations, we arrive at the results

$$EI_z\, d^2/dx^2\,(y + zP/I_z) = M', \quad EI_y\, d^2z/dx^2 = m',$$

where M', m' are what the vertical and horizontal bending moments would be if the spar had its principal axes vertical and horizontal (the principal moments of inertia being still I_z, I_y), and loadings W', w', where

$$W' = W_F, \quad w' = I_y \{ w - W_F P/I_z - W_R Q/J_z \} /(I_y + J_y - P^2/I_z - Q^2/J_z),$$

and J, Q are the values of I, P for the rear spar.

Now M', m' can be obtained by any convenient form of the theorem of three moments. Hence the deflections y, z of the staggered spar can be found. At the middle of a lift bay the first approximations are usually taken to be

$$M' = W'L^2/8, \quad m' = w'l^2/12,$$

where L = distance between inflexions for vertical bending and l = length of drag bay.

For simplicity, we assume that $L = l$ = half the length of a lift bay, and also that the front and rear spars have the same section. The expression for the bending stress reduces to

$$(1/8)\, W_F l^2 y/I_z + (1/24)\, l^2 \{ w - (W_F + W_R)\, P/I_z \}\, (zI_z - yP)/(I_y I_z - P^2).$$

If the section is obtained from a rectangle 4in. × 2in. by shearing it into a parallelogram of angle 60°, the ratio of the stress to that in the rectangular beam has the following values.

The spindled section has $\frac{1}{2}$in. web and flanges measured horizontally and vertically. If the secondary bending strength of the rear spar is neglected, we obtain the ratios given in brackets.

Condition of Loading.	Stress Ratio.	
	Solid.	Spindled.
$W_R = 0$, $w = 0$	1·4 (1·8)	2 (3)
$W_R = 0$, $w = \frac{1}{6} W_F$	1·3 (1·5)	1·6 (1·9)
$W_R = \frac{1}{2} W_F$, $w = \frac{1}{6}\,(W_F + W_R)$ ...	1·5	2·05

II.—SHEAR.

If we use the expression for oblique bending stress given above, the usual method gives, for the mean shear stress σ across any plane cutting off an area A_θ on a base b_θ,

$$\sigma = (A_\theta/b_\theta) \{ \bar{y}\, (S_y I_y - S_z P) + \bar{z}\, (S_z I_z - S_y P) \} /(I_y I_z - P^2),$$

where S_y, S_z are the component shear forces and $\bar{y}$, $\bar{z}$ the co-ordinates of the centre of the area A_θ.

For a rectangular section 4in. × 2in., loaded diagonally, the worst stress is across a plane at 17° to the axis, and is about 5% higher than the stress across the narrowest way. For any direction of loading, there is one plane of no shear stress, which does not coincide with the plane of loading unless it is an axis or a diagonal.

For a square section loaded diagonally, the worst stress is at 23° to the other diagonal and is about 6% higher than the stress across the narrowest way.

For the upright I section, 4in. × 2in., web and flanges $\frac{1}{2}$in., with small values of the inclination α of the shear force to the vertical, the worst stress is very nearly the same as that across the middle of the web. As α increases, there is also considerable shear tending to cut off one flange at the root. The maxima of the two types are equal with $\alpha = 33°$. For a given shear force the worst possible shear stress is with $\alpha = 76°$, and occurs across the flange at $7\frac{1}{2}°$ to the vertical. It is 11% higher than that across the web in vertical loading and 4% higher than that across the flange in horizontal loading.

For the aeroplane wing considered, the component shears at any point are

$$-dM_y/dx, \quad -dM_z/dx,$$

which are found to be at A,

$$R'_A, \quad r'_A(1 - P^2/I_yI_z) + R'_AP/I_z,$$

omitting terms due to difference of fixing moments, we have the approximations

$$R'_A = W'l, \quad r'_A = \tfrac{1}{2}w'l.$$

Taking into account only the lift on the front spar, then with solid staggered spars the worst shear stress is 9% higher than for the rectangular section and occurs at $23\frac{1}{2}°$ to the horizontal. For the spindled section the corresponding figures are 16% and $32\frac{1}{2}°$. The shear across the flange is not considerable for normal conditions of loading.

The author's thanks are due to Miss H. M. Lyon, who has kindly verified these results.

CORRESPONDENCE.

To the Editor of the AERONAUTICAL JOURNAL.

SIR,—In Mr. Ritchie's interesting article on the effect of atmospheric pressure and density, there is one statement which requires correction.

It occurs on page 449, and is to the effect that the boiling point of water falls off approximately 5° F. for each 8,000ft. increase in height. It decreases very much faster than this, the actual rate being 1° F. in 535·5ft.

For further details see my "Notes on the Variation of Atmospheric Conditions with Altitude," published by the Munitions Inventions Department in 1919, and obtainable at H.M. Stationery Office for the modest sum of 6d.—Yours faithfully,

C. F. DENDY MARSHALL.

REVIEWS.

Meteorology. A. E. M. Geddes. (Blackie and Son, Ltd. 21s.)

The number of elementary text books of Meteorology is now reaching a considerable size, but Dr. Geddes' addition to this number is justified by the very much wider range of subjects which he covers, beyond those usually found in such books. Thus we find such diverse subjects as the temperature at the bottom of oceans; the composition of the air at great heights; sound ranging for artillery; the origin of the aurora, and meteorological optics, all touched upon in addition to the usual subjects of meteorological text books. This wide range of subjects makes it necessary to treat each rather briefly, the author's aim being to give a general review of the whole subject. It is therefore unfortunate that references to original papers and more detailed works on the various subjects are so few.

There are several paragraphs in the book which we would quarrel with, though these hardly affect its general character. On page 162 there occurs this remarkable sentence, dealing with cloud droplets:—". . . . the droplets are solid, not hollow. For if they were hollow, the pressure inside, on account of their size, would be very much greater than that outside by reason of surface tension, and the drops would burst asunder." Now in the first place, we never knew anyone who supposed they were hollow, so that the statement seems rather unnecessary, but the latter part of the sentence is a truly remarkable physical deduction!

Again, on page 40 we find the following cryptic remark, for which the physical reasoning might have been as interesting as that above:—"The earth is not a regular sphere, but a spheroid, so that the attraction of the sun does not pass through the centre. The result is that the plane of the equator . . . is not that of the earth's orbit, the two planes intersecting at 23°."

Further, on page 57 the "greenhouse effect" (*i.e.*, the difference in the transparency of glass for visible and infra red radiation) is given as being the sole cause why a mercury thermometer exposed to the sun reads higher than true air temperatures. Does the author suppose that if the thermometer bulb were painted black on the outside, so that there was no "greenhouse effect," then a thermometer would always read true air temperatures even when exposed directly to the sun?!

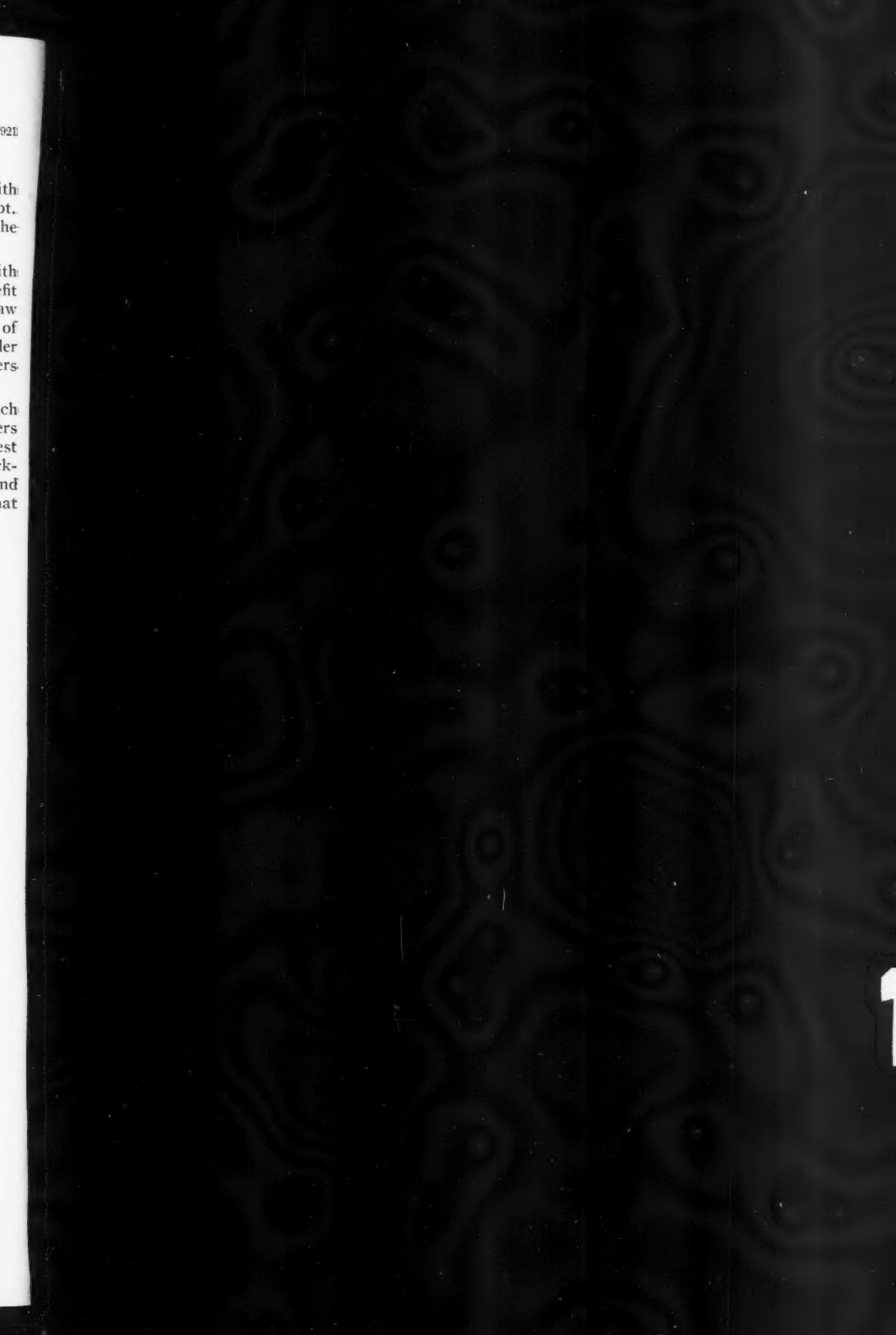
The author's style is not always very clear, as instanced by the description of atmospheric pressure. In the opening paragraph of Chapter V., after discussing this subject, atmospheric pressure is finally defined as "either the elastic force or the weight it supports." Would the average reader's idea of atmospheric pressure be clearer, we wonder, after or before he read this definition?

These are but a few instances of many other somewhat unfortunate statements, which it is hoped the author will rectify in future editions; they do not, however, greatly affect the character of the book, which we hope will be useful to many.

Clouds. G. A. Clarke. (Constable and Co. 21s.)

Mr. Clarke is already well-known to meteorologists by the excellence of his drawings and photographs of clouds, and they, together with the general public, will therefore welcome this book in which he has reproduced between seventy and eighty of his cloud photographs and a few coloured drawings. The photo-

graphs are selected to illustrate all the various types of clouds, beginning with the highest cirrus and ending with the low nimbus. Some half-dozen of Capt. Douglas' photographs of clouds taken from an aeroplane are also added at the end.

There are five brief chapters at the beginning of the book dealing with the classification of clouds, the causes of their formation, etc., for the benefit of the general reader, and therefore of a semi-popular nature. Sir Napier Shaw also contributes a short paper. One excellent feature of the letterpress part of the book is that references to original papers dealing with the subject under review are constantly given, and are sure to prove very useful. Other writers might with great advantage follow Mr. Clarke's example in this matter.

Cloud photography is a special art, and one hardly ventures to criticise such a master of it as Mr. Clarke, but it appears as if most cloud photographers rather lose the sense of proportion. When one sees, for example, the finest cobweb-like cirrus shown as a hard contrast of dead white on a black background (a result made possible by the great development in modern plates and screens), one cannot but feel their eagerness to show every detail has somewhat overbalanced the wish to give a picture of the cloud as it really appears.